OIL SANDS TAILINGS SLUDGE ABANDONMENT

DRY LAND RECLAMATION STUDY

[Part of Energy, Mines and Resources Cost-Shared
Energy Conversion Program and Part of the
Federal Panel on Energy Research and
Development (PERD)]

Final Report by

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Work on the project was conducted under the auspices of the Canada Centre for Mineral and Energy Technology, Energy, Mines and Resources Canada.

SSC FILE NO.: 002SQ.23440-1-9152

CONTRACT FILE NO. 23440-1-9152/01-SQ

135 PP

CANMET SCIENTIFIC AUTHORITY: A. MacLEOD

MICROMEDIA

JULY 1992

93-01572/

EXECUTIVE SUMMARY

A comprehensive fine tails abandonment research program was conducted by Suncor Inc., Oil Sands Group during 1991/92. The Suncor program included an investigation of potential environmental impacts associated with dry land reclamation options for the eventual abandonment of fine tails wastes resulting from the extraction of bitumen (oil) from oil sands.

The Dry Land Reclamation project was designed to assess the potential impact on the soils resulting from the inclusion of fine tails in the soil amendment. Additionally, an assessment was made on the leachates which could be expected to emanate from these fine tails amended soils.

The initial section of this report provides summary details on the Dry Land Reclamation research project. A second section describes the quality assurance/quality control (QA/QC) program which was an integral component of this and all other Fine Tails Abandonment Research projects. A third section provides a summary of the investigative results of the project. The final section of this report is comprised of a copy of the original consultant report for the Dry Land Reclamation research project.

The results of this research project indicate that there are definable impacts associated with the incorporation of fine tails into the soil amendment mixtures. These impacts include changes to soil physical and chemical characterisitics as well as significant or potentially significant impacts on soil toxicological properties.

This study demonstrated that significant levels of microbial activity occur within soils which had been amended with fine tails. Additionally, the study detailed the negative impacts which fine tails have on the nitrifying potentials in these soils.

The simulation of rainfall component of this project demonstrated that the addition of fine tails to the soil amendments has several impacts including negative effects on the movement of water into the soils, soil water retention, and soil hydraulic conductivity.

Leachate water chemistry data collected during this study showed impacts of the fine tails on levels of nutrients, metals, and oil and grease concentrations. Changes in leachate quality were demonstrated to occur very rapidly with improvements in water quality noted between the original eight day collection cycle and a subsequent collection cycle.

Toxicological assessments of the leachates collected from the soil treatments used during this study showed variations both between collection cycles and leachate sources. Leachates from the original collection cycle were more toxic as were leachates from soil amendments containing fine tails.

The results of this study on the effects of incorporating fine tails into a soil amendment mixture demonstrate that the fine tails amendment procedure results in significant or potentially significant impacts. However, the results from this and previous studies also suggest that these impacts are reduced with time as biodegradative processes occur within the soil.

The leachate from fine tails amended soils may also have significant or potentially significant impacts on the environment. The quality of these leachates will change with time as biodegradative processes effect both the quality of the parent material (the fine tails amended soil) and the leachates themselves.

Methods of mitigating the impacts associated with incorporating fine tails into reclamation soil amendments are discussed.

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I. Effect of dry land reclamation of fine tails on soil and leachate quality. Prepared by EVS Consultants for Suncor Inc., Oil Sands Group by S.H. Hamilton and M. Shum. 50 pp. + Appendices.

SUNCOR 1991/92 OIL SANDS TAILINGS SLUDGE (FINE TAILS) ABANDONMENT RESEARCH PROGRAM

DRY LAND RECLAMATION STUDY

I. INTRODUCTION

Suncor Inc., Oil Sands Group (Suncor) has an active research and development program designed to assess and resolve issues associated with the final handling of fine tails (tailings sludge) wastes which result from the current process employed to extract bitumen from oil sands. The Suncor research program includes investigations of two primary handling options: 1. Abandonment of fine tails within a wet landscape system in which the fine tails are placed within a constructed pond, then capped with water; and 2. Abandonment in a dried state in which processes such as freeze-thaw, aggressive drainage and/or vegetative dewatering are used to dewater the fine tails as part of a dry land disposal system.

Dry option investigations at Suncor have included approaching the research in two directions: 1. The evaluation of optimal physical processes for dewatering and handling the fine tails; and 2. The evaluation of potential environmental impacts associated with either the dewatering process or residual contaminants within the dried fine tails.

Suncor entered into a contractual agreement with the Canadian Centre for Mineral and Energy Technology - MSL Division to investigate potential impacts associated with leachates from reclamation land surfaces where fine tails had been incorporated into the soil amendment mixture. This Dry Land Reclamation Project was a follow-up to one of the 1991 projects conducted by Suncor under CANMET Contract 23440-1-9076/01 SQ. to assess the reclamation potential of fine tails amended soils (Gulley, 1992). The 1991 project involved the revisiting of a Suncor study site where the potential for incorporating fine tails as a component of soil amendment mixtures had been investigated in a 1979-84 study by Norwest Soil Research Ltd.

The results of the 1991 investigation on the fine tails amended soils showed that the addition of the fine tails to the soil amendment mixture continued to have a negative impact on plant productivity, 11 years following the application of fine tails. However, the magnitude of the impact had decreased from those impacts noted during the original 1979-84 study indicating that progressive bioremediation (i.e., microbial degradation) was impacting the amended soils (Hamilton and Shum, 1992).

The 1991 study highlighted a further requirement to assess the potential environmental impacts associated with the application of fine tails to a soil amendment mixture. To enable Suncor to continue the assessment of the long-term effects which were documented for the 1979-84 study area, the four soil treatments investigated during that study were recreated for investigation in this study. Suncor established this research program to obtain specific information for each of the soil treatments on the following parameters:

a) What are the physical and chemical characteristics of the fine tails amended soils as compared with soil amendments without fine tails?

b) What level of toxicity was evident for the four soil treatments?

c) What levels of microbial activity were recorded for each soil treatment?

d) What influence did the fine tails have on nitrification? and,

e) What was the chemistry and toxicity of leachate collected from the four treatments?

Resolution of these issues would assist Suncor in further defining potential environmental impacts associated with dry option handling of fine tails.

This final report presents research project data in two formats. The initial section of the report provide an overview and summary of the Dry Land Reclamation Study. Attached as an Appendix to this report is the final project report issued by the primary consultant employed by Suncor for its Fine Tails Abandonment Research Program.

II. SUMMARY OF THE DRY LAND RECLAMATION PROJECT

The Suncor Dry Land Reclamation Project involved a laboratory investigation of the effects of incorporating fine tails within soil amendment mixtures. The soil mixtures investigated in this study replicated the four treatments investigated originally by Suncor in a 1979-1984 Norwest Soil Research Ltd. study and subsequently in a 1991 assessment of dry land reclamation using fine tails as a soil amendment (Hamilton, S.H. (1991) in Gulley, 1992).

The soil mixtures investigated during these studies included:

1. Treatment 1 - 100% tailings sand (control).
2. Treatment 2 - 50% tailings sand and 50% muskeg.
3. Treatment 3 - 25% fine tails, 37.5% tailings sand and 37.5% muskeg (designated as low fine tails).
4. Treatment 4 - 43% fine tails, 28.5% tailings sand and 28.5% muskeg (designated as high fine tails).

The Hamilton and Shum report (1992), attached as Appendix I of this report, details the methods and materials employed for the:

1. Preparation of the four soil mixtures;
2. Design of the leaching columns; and
3. Simulation of rainfall.

Figures 1, 2 and 3 from Hamilton and Shum (1992) provide diagrammatic details of the apparatus employed to simulate rainfall and collect leachates for this study.

The evaluation of the potential for environmental impacts resulting from the incorporation of fine tails into the soil amendment mixtures were facilitated through laboratory analyses of the soil amendment treatments and leachate waters collected from the treatments.

Analyses were conducted on the following parameters:

1. Soils
    a. soil chemistry characteristics,
    b. soil physical characteristics,
    c. Nematode bioassays,
    d. *Hyalella azteca* toxicity tests,
    e. CO_2 evolution determinations, and
    f. nitrifying potential evaluation.
2. Leachate Waters
    a. leachate chemistry,
    b. Microtox™ testing, and
    c. *Daphnia magna* toxicity tests.

The various analyses undertaken during this project were conducted at one of the following laboratories: Pacific Soil Analysts Inc., Analytical Services Laboratories Ltd., Soilcon Laboratories Ltd., BioQuest International, Inc., Beak Consultants Ltd., or EVS Consultants. All laboratory analyses were conducted employing recognized analytical methodologies and quality assurance/quality control practices.

Section III of this report provides details on the QA/QC programs of two of the principal analytical laboratories used during this research project.

III. QUALITY ASSURANCE/QUALITY CONTROL (QA/QC) PROGRAM

The chemical, biological and toxicological assessments conducted as components of this research project were primarily conducted by two firms - ASL (Analytical Services Laboratories Ltd., Vancouver, BC) and E.V.S. Consultants (North Vancouver, BC). These companies were required to include a rigid Quality Assurance/Quality Control Program for all analytical and toxicological work undertaken as part of the Suncor Research Program. Additionally, details of the QA/QC programs were requested from each firm. The information provided by the firms on their QA/QC Programs is presented below.

Environmental Toxicological Assessments - E.V.S. Consultants

The E.V.S. Consultants bioassay laboratory is certified under the Washington State Department of Ecology laboratory accreditation program (because at present there is no formal accreditation program for bioassay laboratories in Canada). E.V.S. Consultants have developed a rigorous in-house QA/QC program which ensures complete documentation of data; data computation standardization and minimization of possible errors in computation and reporting of results. The E.V.S. Consultants in-house QA/QC officer conducts routine random checks on laboratory reports to ensure defensibility of data. The following general QA/QC guidelines apply to all bioassays:

Negative Controls - All bioassays are conducted using well-established negative (clean) controls. For every bioassay, one chamber or series of test chambers must contain clean diluent water (or clean diluent water and clean sediment) only. The complete bioassay series is repeated if more than 10% of the control organisms die or show evidence of sublethal effects.

Positive Controls (Reference Toxicants) - All bioassays include positive (toxic) controls, conducted with well-established standard reference toxicants. For organisms obtained from outside sources, a positive control is tested for each new batch obtained. For organisms obtained from in-house laboratory cultures, positive controls are performed on a monthly basis. Control charts are constructed to record the cumulative mean response value and upper and lower control limits (mean ± 2SD) for the reference toxicant.

Test Organisms - Only healthy organisms of similar size and life history are used for bioassays. All test organisms used for a batch of tests must be from the same source. Records of collection, shipping and holding are maintained for all species obtained outside of the laboratory.

Replication - The number of replicates required varies from one test protocol to another, but should always be sufficient to account for variability in test organism response. Unless otherwise specified in the experimental design, each treatment in a bioassay series must begin with the same number of replicates.

Water Quality Measurement/Maintenance - Bioassays involving exposure of organisms in aqueous media require that the media be uncontaminated and that proper water quality conditions be maintained to ensure the survival of the organisms, and to ensure stress is not exerted on the organisms, unrelated to the test materials. Appropriate water quality parameters must be measured at the start and end of a test and regularly for the duration.

Standard Laboratory Procedures - Standard laboratory procedures must be followed in all testing. These include proper documentation, proper cleaning, avoidance of contamination and maintenance of appropriate test conditions. All unusual observations or deviations from established procedures must be recorded and reported.

Biological Assessments - E.V.S. Consultants

The following QA/QC procedures are rigorously followed for both biological sorting and taxonomy:

- Complete sorting (including resorting), processing and/or laboratory records for each sample;
- Twenty percent of all samples will be randomly selected and resorted by individuals different from those who conducted the original sorting to check sorting efficiency and accuracy (initial sorting done by one firm; QA/QC done by EVS). Sorting QA/QC will be done using 25 power magnification for benthos and 400-1000 x for algae. A sample will pass if the number of organisms found during the QA/QC check does not represent more than 5% of the total organisms found in the entire sample. If the number of the organisms found is greater than 5% of the total number, the entire sample will be resorted. In addition, all sorting work performed by the sorter responsible for the error will be checked;
- All samples will be held for one year and will be available thereafter if desired;
- A voucher collection will be prepared consisting of specimens representative of each species (or lowest taxonomic unit of classification). Verified specimens will be added to the reference collection assembled for the project;
- Taxonomic references used for the identification of all organisms will be cited in the appendix to the final report;

- Taxonomic QA/QC is achieved by sending 5% of all samples out for independent reidentification by qualified regional expert(s); and
- Any unusual and/or ambiguous identifications will be submitted to appropriate experts in that area; for example, botanists at the University of Alberta.

Chemical Analyses - ASL

The methodology that will be utilized for these projects will be consistent with the requirements of the requisite regulatory agencies (Federal and Provincial). The following provides summary statements:

- Convention Tests (nutrient, physical test, major ions, etc.) by APHA (American Public Health Association) and Alberta Environment published methods.
- Metals - by ICP (inductive coupled argon plasma) except for mercury which will be by cold vapour atomic absorption.
- All specific organics will be analyzed in accordance with methods published by the Ontario Ministry of Environment and the U.S. EPA. In all cases the final extract analysis will be by capillary column gas chromatography / mass spectrometry.
- In all cases, attempts will be made to meet required detection limits rather than simply dilute the samples to minimize matrix efforts. Our PAH and phenolics methods involve proper clean ups to remove interferences from aliphatic hydrocarbons.

Quality Assurance/Quality Control

The U.S. EPA defines Quality Assurance (QA) as "the total program for assuring the reliability of monitoring data". Quality Control (QC) is limited to "the routine application of procedures for controlling the measurement process". QC is primarily concerned with the tools of the measurement system.

Reagents of the highest quality and checked for purity, strength, deterioration with time, and contamination. Class A volumetric glassware is thoroughly cleaned and calibrated when necessary. Balances are frequently checked with certified weights and records kept. All instruments are calibrated on a routine basis, with the maintenance of appropriate standards and operation logs on performance.

The QA program includes the analysis of quality assurance samples to define the precision and accuracy of the method for the type of sample under investigation. For environmental analyses, the following quality assurance samples are commonly employed:

- Method Blank - usually distilled water with added reagents, which is carried through the entire analysis as a check on laboratory contamination (also called a reagent blank).

- Duplicate - a homogenous sample is split either in the filed or in the laboratory with the duplicate presented to the analyst as an additional sample to check for precision. If more than two splits are analyzed the term replicate is normally used.

- Check Standard - a procedure is standardized with calibration standards prior to analyzing the samples. The analytical response to the standards should be checked by frequency analyzing one or more standards along with the samples. The check standards should be prepared independently of the calibration standards.

- Surrogate Compounds - are used when gas chromatography/mass spectrometry procedures are employed. The surrogate standards are deuterium labelled compounds that are added to the samples prior to the extraction. They can be quantified independently of the authentic compounds. In this way quality assurance is provided for each sample.

- Spike - a known amount of analyte is added to a sample to provide information on matrix effects and apparent accuracy. Internal Standards are also used in this manner.

- Standard Reference Material - a material that contains a known concentration of the analyte in question. Based upon reliable documentation of the analyte concentration, a reference material is certified by agencies such as the National Bureau of Standards and the National Research Council.

ASL believes that a good quality assurance program is imperative in producing data of known and acceptable quality. Without a thorough and consistent QA program the data cannot be considered complete. The use of quality assurance samplers for this project involving 5 samples per batch is outlined below:

5	Samples
1	Duplicate
1	Standard Reference Material (or Spike if not available)[1]
1	Method Blanks
5	Surrogate Spikes (deuterium labelled compounds)[2]

[1] In the case of many of the conventional tests and metals external reference materials are available

[2] For those analyses carried out by GC/MS

This Quality Control program is very extensive. Therefore, the information generated allows the determination of precision, accuracy and contamination control for all measurements. All data is normally presented along with sample results in the final reports.

Additional Quality Assurance measures include the supply and use of sample submission forms so pertinent field information is transferred to the laboratory. In addition, a representative from ASL will ensure that appropriate handling and storage of samples prior to pick up. If deemed appropriate, transportation blanks are supplied for handling in field to ensure that field contamination is not an issue.

Also important is the participation by ASL in numerous inter-laboratory programs organized by agencies such as Environment Canada, U.S. Environmental Protection Agency, B.C. Ministry of Environment and the National Research Council. ASL is officially registered with the B.C. Ministry of Environment and is a member of the Canadian Association of Environmental Analytical Laboratories (CAEAL).

IV. SUMMARY OF THE INVESTIGATIVE RESULTS OF THE DRY LAND RECLAMATION RESEARCH PROJECT

This section provides a summary of the investigative results of the various analytical procedures conducted on the treatment soils and collected leachates. Complete details on the investigative results are provided within Section 3 of the Hamilton and Shum (1992) report attached as Appendix I of this report.

A. Soils

The results of this investigation on dry land reclamation options show that the application of fine tails to the soil amendment mixture has an impact on soil physical and chemical characteristics and a significant impact, or potentially significant impact on soil toxicological properties. Study results also demonstrated microbial activity and impacts on nitrifying potentials.

1. Soil Chemical and Physical Properties

The addition of fine tails to the soil amendment mixtures resulted in increases in total carbon while available nitrates were lower. Cation exchange capacity was also higher in fine tails treatments.

2. Soil Bioassays

Soil bioassays were performed on the soils prior to leaching. The species used in these bioassays included the freshwater amphipod (*Hyalella azteca*) and the soil nematode (*Panagellus redivivus*). Test results indicated that the fine tails amended soils had a greater occurrence of toxicity.

3. Microbiology

Results of the assessment of CO_2 evolution from the four soil treatments indicated a significantly difference between rates from the four soil treatments. Additionally, with Treatments 3 and 4 (fine tails additions) there was a flush of CO_2 in the first week. These data indicate that there were active microbial degradation processes occurring within the treatments.

Assessment of the nitrifying potential for the four treatments showed a complete inhibition of nitrification in the fine tails amended soils. The data suggest that certain hydrocarbon compounds within the fine tails are toxic to nitrifying bacteria.

B. Leachate Water

The simulation of rainfall component of this project demonstrated that the addition of fine tails to the soil amendments has several impacts including effects on the movement of water into the soils, water retention and hydraulic conductivity. Soil amendments with fine tails had reduced values for all of these parameters.

1. Leachate Water Chemistry

Water chemistry evaluation of leachate collected during the study demonstrated the impact of fine tails additions to the soil amendments. Levels of nutrients, metals and oil and grease concentrations differed among the four treatments both during the initial 8 day rainfall cycle and the subsequent 8 day cycle. Concentrations of some contaminants of concern were reduced to below guideline values following the second cycle.

Oil and grease levels were high in all treatments (reflecting residual concentrations within all soil amendment materials) with a decrease in concentrations recorded during the second cycle for all but the treatment with high fine tails application levels (Treatment 4). Hydrocarbon levels were significantly lower in the leachates than in the parent soil amendment mixtures.

2. Leachate Bioassays

Toxicological assessments of the leachates were conducted by performing Microtox™ and a modified 21 day *Daphnia magna* tests. Results from the Microtox™ test were interpreted as suggesting that the soil mixtures have both a positive and negative influence on bacteria luminescence (Section 3.6 - Hamilton and Shum - Appendix I). The positive influence was identified as the dissolved organic carbon acting as a substrate for the bacteria. However, the negative influence was that some component of the fine tails was acting as a source of toxicity to the bacteria.

Results from the modified 21 day *Daphnia magna* tests showed significantly lower reproduction levels for daphnia in leachates collected during the first rainfall cycle as compared with the leachate collected during the second cycle. Reproduction in leachates from the second cycle were all higher than in the test control.

V. DISCUSSION OF THE INVESTIGATIVE RESULTS OF THE DRY LAND RECLAMATION RESEARCH PROJECT

The results from this study on the effect of incorporating fine tails into a soil amendment mixture demonstrate that the fine tails amendment procedure results in significant or potentially significant impacts. However, the results from this and previous studies suggest that these impacts are reduced with time as biodegradative processes occur within the soil.

The magnitude of impacts associated with the incorporation of fine tails into soil amendments may be reduced by area management practices. Applications of fertilizers will assist through the provision of nutrients essential for biodegradative activities.

The potential for leachates from fine tails amended soils to impact the environment are also significant or potentially significant over the short term. Leachates and the potential to generate toxic leachates from fine tails amended soils would also be affected by biodegradative processes active in the area.

The impacts resulting from leachates may be mitigated through operational management techniques including:

a) restricting the volumes of fine tails added to the soil;

b) limiting the volumes of leachate generated by restricting water flow to the area; and

c) controlling any leachates generated via collection systems which channel liquids to treatment areas such as constructed wetlands.

VI. LITERATURE CITED

Gulley, J.R. 1992. Study of oilsands sludge reclamation under the tailings sludge abandonment research program. [Part of Energy, Mines and Resources cost-shared energy conversion program and part of the Federal Panel on Energy Research and Development (PERD)]. 27 pp. + Appendices.

Hamilton, S.H. and M. Shum. 1992. Effect of dry land reclamation of fine tails on soil and leachate quality. Prepared by EVS Consultants for Suncor Inc., Oil Sands Group. 50 pp. + Appendices.

VII. APPENDIX

Appendix No.

I. Effect of dry land reclamation of fine tails on soil and leachate quality. Prepared by EVS Consultants for Suncor Inc., Oil Sands Group by S.H. Hamilton and M. Shum. 50 pp. + Appendices.

FINAL REPORT

EFFECT OF DRY LAND RECLAMATION OF FINE TAILS ON SOIL AND LEACHATE QUALITY

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May 1992

EXECUTIVE SUMMARY

In this study, fresh mixtures of fine tails, sand and muskeg were prepared to simulate field conditions under a dry reclamation scenario whereby fine tails would be applied to the land surface.

We have concluded that the environmental risk that land treatment of fine tails would have on groundwater and surface water quality is manageable. Pilot-scale field assessments would help to verify this and would be necessary to refine the management practices required for full scale land treatment.

Although fine tails are toxic when first applied to soils, they will be biodegraded and can be expected to ultimately detoxify. Processes of biodegradation can be assisted by careful management including an annual fertilization program. Leaching of contaminants to groundwater should not be a serious problem if the areas used for land treatment are small and/or are staggered over time among adjacent "cells". The effects on groundwater quality from the application of fine tails to large areas are not known. The results from this study support previous recommendations that the "low" range (5-6 cm depth) of fine tails application shows promise, but that higher loading rates could be too difficult to manage (Hamilton, 1992).

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ACKNOWLEDGEMENTS

This report was written by Dr. Hugh Hamilton and Mr. Michael Shum, and reviewed by Mr. Peter Nix. Technical input was received from Dr. André Sobolewski, Ms. Kathie Vilkas, Ms. Lori Suffredine, Ms. Bev Kelleman, and Cathy McPherson. The report was word processed by Jackie Gelling and produced by Leanne Cook. We wish to thank Dr. Bernie Zebarth of Agriculture Canada in Agassiz, B.C. for his comments on experimental design.

Citation

Hamilton, S.H. and M. Shum. 1992. Effect of dry land reclamation of fine tails on soil and leachate quality. Prepared by EVS Consultants for SUNCOR Inc., Oil Sands Group. pp 50.

1.0 INTRODUCTION

1.1 Background

Suncor Inc., Oil Sands Group (Suncor) presently utilizes a number of large tailings ponds for tailings disposal. Most of the tails contained in the ponds are sand size (diameter 0.02 mm to 2.0 mm), and settle quickly to the tailings pond bottom. However, the tailings slurry also contains fine tails (silt and clay size, <0.02 mm) which tend to remain in suspension and mix with residual bitumen to form a viscous slurry. Whereas the larger tails are relatively clean and can be used to construct dykes and backfill pits, the fine tails are considered a waste product. There are presently two general options for treating fine tails following mine decommissioning: wet reclamation and dry reclamation. With wet reclamation, the fine tails would be retained in a constructed pond capped by a layer of water. Under the dry reclamation scheme, the fine tails would be spread over the land surface and the water allowed to evaporate and/or drain off to collection areas. The material would then be revegetated using current reclamation methods employed at the site.

The wet reclamation scheme is the currently preferred option for the disposal and management of most of the fine tails. However, even if wet reclamation is selected as the prime strategy, there will likely be considerable volumes of fine tails requiring dry reclamation techniques (i.e., land disposal). This is because some fine tails may not be well suited for wet reclamation due to the potential for high levels of methane production.

In 1991 a follow-up study was conducted on a series of plots which had been established on a northern section of Tar Island Dyke (Hamilton, 1992). The plots were established to assess the potential value of fine tails as a soil amendment on reclamation sites (Rowell, 1984). The soils on dykes and other reclaimed areas on the Suncor site are generally a poor medium for plant growth due to excessive draughtiness, poor structure, low nutrients, and poor pH buffering capacity. Fine tails which had been proposed as a soil amendment that could remedy these problems, were incorporated into the soils on study plots. These plots were seeded then monitored for soil and vegetation properties until 1984. The plan to use fine tails as soil amendment was abandoned based on both the extreme difficulties in handling the fine tails, and the results of this study which demonstrated that plant growth was inhibited by high sodicity and high bitumen levels.

The emphasis of the 1979-84 study, which is referred to here as the Norwest study, was on fine tails as a possible soil amendment, rather than an assessment of the potential of dry land reclamation as a disposal option. The field study which was conducted on the same plots in 1991 was intended to assess the reclamation potential of the fine tails amended soils, eleven years after the fine tails were applied. Towards this end, the soils were sampled and tested for chemical and physical properties, microbial activity, and toxicity. As well, differences in plant productivity and nutrient uptake in amended and control plots were assessed. It was concluded that the addition of fine tails to reclaimed soils continued to have a negative impact on plant productivity, 11 years following application. However the magnitude of the negative effect had diminished considerably since 1980-83. The data indicated that progressive bioremediation (i.e., microbial degradation of oily residues) has the potential to further reduce differences between soils amended with fine tails and those without. Low levels of nitrate appeared to be the major limiting factor, both for plant growth and microbial activity. A tentative conclusion was that a fine tails loading rate of about 5.5 cm depth was feasible.

No information was obtained during the Norwest study on the potential environmental impacts associated with fine tails disposal on land because the study was not designed to address waste disposal issues. Although the follow-up investigation in 1991 did address questions of soil toxicity and microbial decomposition, important questions remained to address the evaluation of land disposal of fine tails.

1.2 Study Objectives

The objectives of this study were to:

- prepare laboratory soil mixtures of sand, muskeg, and fine tails that replicate conditions at the start of the Norwest study;
- characterize and compare the physical and chemical properties of the four soil treatments.;.
- compare microbial activity between treatments as expressed by carbon dioxide evolution;
- determine the toxicity of the four soil treatments using a nematode (*Panagrellus redivivus*) bioassay and a 10-day *Hyalella azteca* bioassay;
- determine the influence of fine tails on nitrification; and,
- determine the chemistry and toxicity (Microtox™, *Daphnia magna*) of leachate collected from the four treatments.

2.0 METHOD AND MATERIALS

2.1 Collection of Soil Materials

Tailings sand and muskeg were obtained from outdoor stockpiles at the Suncor facility near Fort McMurray in January, 1992. The fine tails were taken from Suncor Tailings Pond 2 at the same time. The materials were placed in metal containers and shipped to EVS Consultants in North Vancouver, B.C.

2.2 Preparation of Soil Mixtures

Four bulk soil mixtures were prepared, one for each of the four treatments, in the volumetric proportions as follows:

Treatment 1 - 100% sand (control)
Treatment 2 - 50% sand and 50% muskeg (normal reclamation practice)
Treatment 3 - 25% fine tails, 37.5% sand and 37.5% muskeg (low fine tails)
Treatment 4 - 43% fine tails, 28.5% sand and 28.5% muskeg (high fine tails)

These treatments are sometimes referred to as T1, T2, T3, and T4 in the text.

The proportions utilized in Treatments 2, 3 and 4 were intended to simulate the average conditions in the field plots in 1979. Prior to preparing treatments, tailings sand and muskeg were sieved through 1.95 cm^2 mesh to remove large stones. Due to the very high moisture content of the fine tails, 211% (dry weight basis), Treatments 3 and 4 were initially in the form of a slurry. Additional tailings sand was added to these treatments to improve the consistency so that they could be handled.

Each treatment was immediately amended with a commercial fertilizer (Greenleaf Shur-gro 20-20-20 soluble plant food) at an application rate of 71.4 kg/ha. This served two purposes: to simulate conditions that existed at the start of the Norwest field study; and, to revitalize the indigenous soil microbial populations which may have been affected by anaerobic conditions likely experienced during transportation from Fort McMurray.

2.3 Design of Leaching Columns

A total of 12 leaching columns were built to accommodate three replicates of four treatments. Columns were made from 20 L plastic buckets (approx. 28 x 37 cm) with the bottoms removed (Figure 1). The centre of each lid was removed and used to attach 200 µm mesh to the bottom of each bucket to support the soil mixtures while permitting leachate to pass through. Large plastic funnels were then attached to the lids to channel the leachate to glass 1 L collection jars through a plastic hose. All plastic buckets, lids, Nitex mesh, funnels, and tubing were allowed to soak for 5 days in flowing dechlorinated water. Glass collection jars were rinsed with 10% nitric acid, twice with distilled water, acetone, and finally distilled water 5 times to remove metals and organics.

The completed columns were placed in a rack in three rows of four columns. Rain-drip racks were constructed from 3/4" Schedule 40 PVC pipe which were drilled with 1/16" holes spaced at 10 cm intervals (Figure 2). Three rain-drip racks were required, each suspended over a row of columns. Additional mesh or diffuser screens, 40 x 135 cm, were constructed, using window mesh and PVC, to reduce the raindrop size and facilitate dispersion of moisture over the soil surface. These screens were placed between the rain-drip racks and the columns. The rain-drip and window mesh racks were suspended from the ceiling by 1 x 2 inch pieces of lumber with adjustable hinges and then levelled (Figure 3).

2.4 Pre-experiment Sampling

Soil mixtures were loaded into the columns, transported to the EVS Marine Lab, where they were acclimatized for 10 days at 17°C. Leachate from Treatments 3 and 4 were collected during this period and stored at 4°C. The day prior to initiation of rainfall, Treatments 1 and 2 were brought up to field capacity by adding 3 L of dechlorinated water to each column. Additional water was not required as drainage from the columns was rapid. Initial water collected from Treatments 1 and 2 was stored with the other collected leachates. Soil samples for laboratory analysis were collected from each column and stored in acid-rinsed glass jars at 4°C.

2.5 Rainfall Simulation

With conventional leaching column studies, soil is saturated and placed under a constant head of water. While this procedure is effective in leaching water soluble compounds, it does not attempt to mimic natural conditions where rainfall is delivered in discreet events and treatments usually draining to field capacity between events. Since the objective of this investigation was to simulate field conditions in an area where (the

Figure 1. Leaching Columns

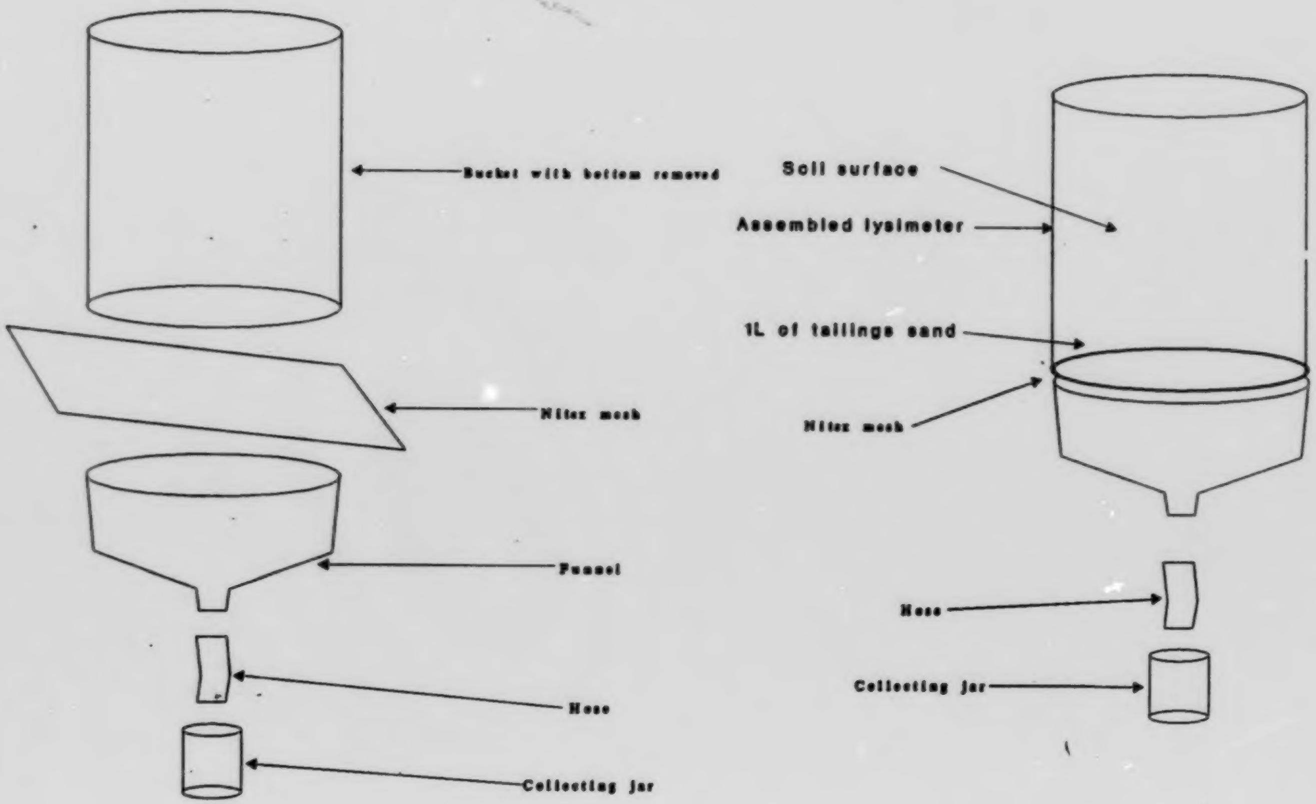

Bucket with bottom removed
Nitex mesh
Funnel
Hose
Collecting jar
Soil surface
Assembled lysimeter
1L of tailings sand
Nitex mesh
Hose
Collecting jar

Figure 2. Rain-drip Racks

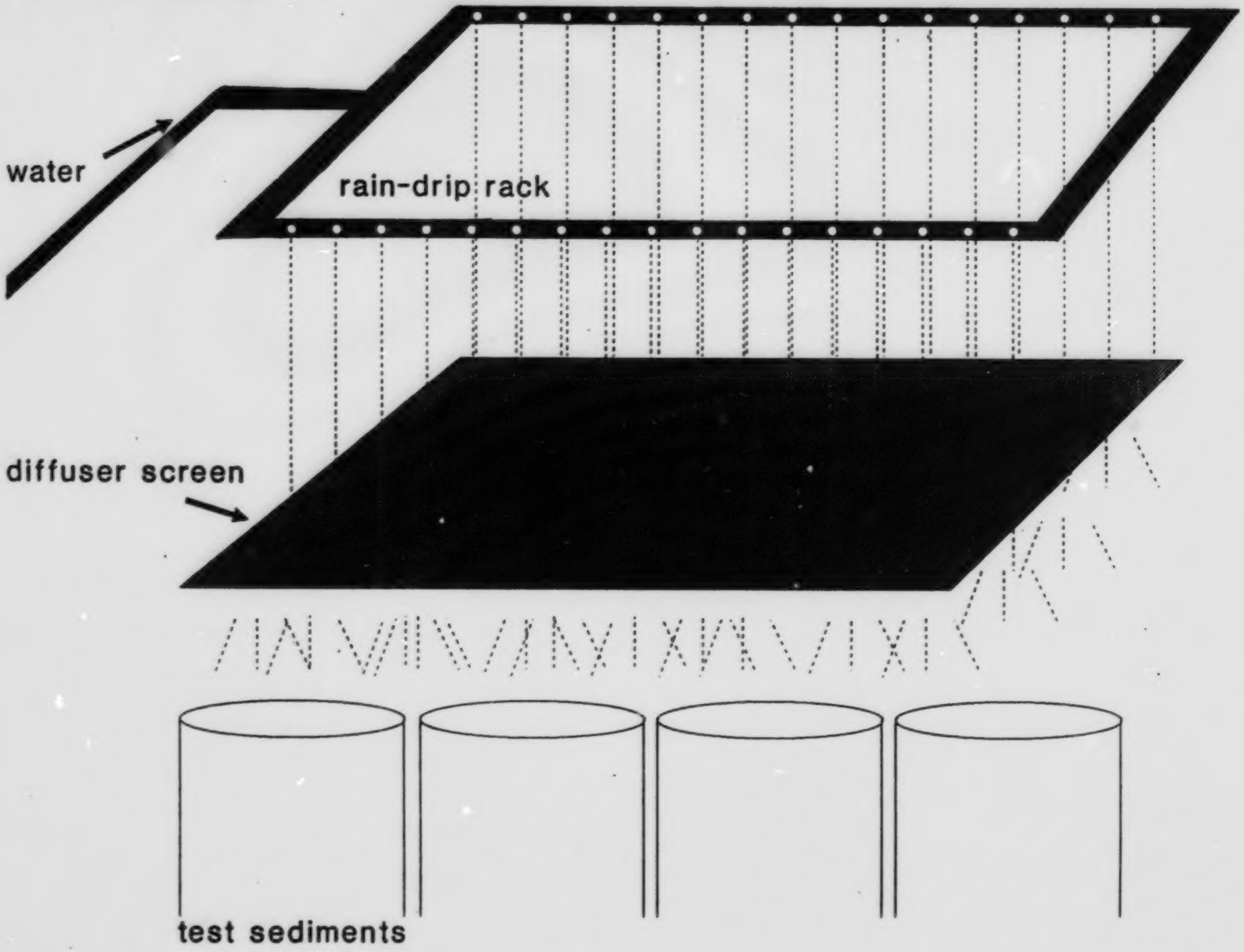
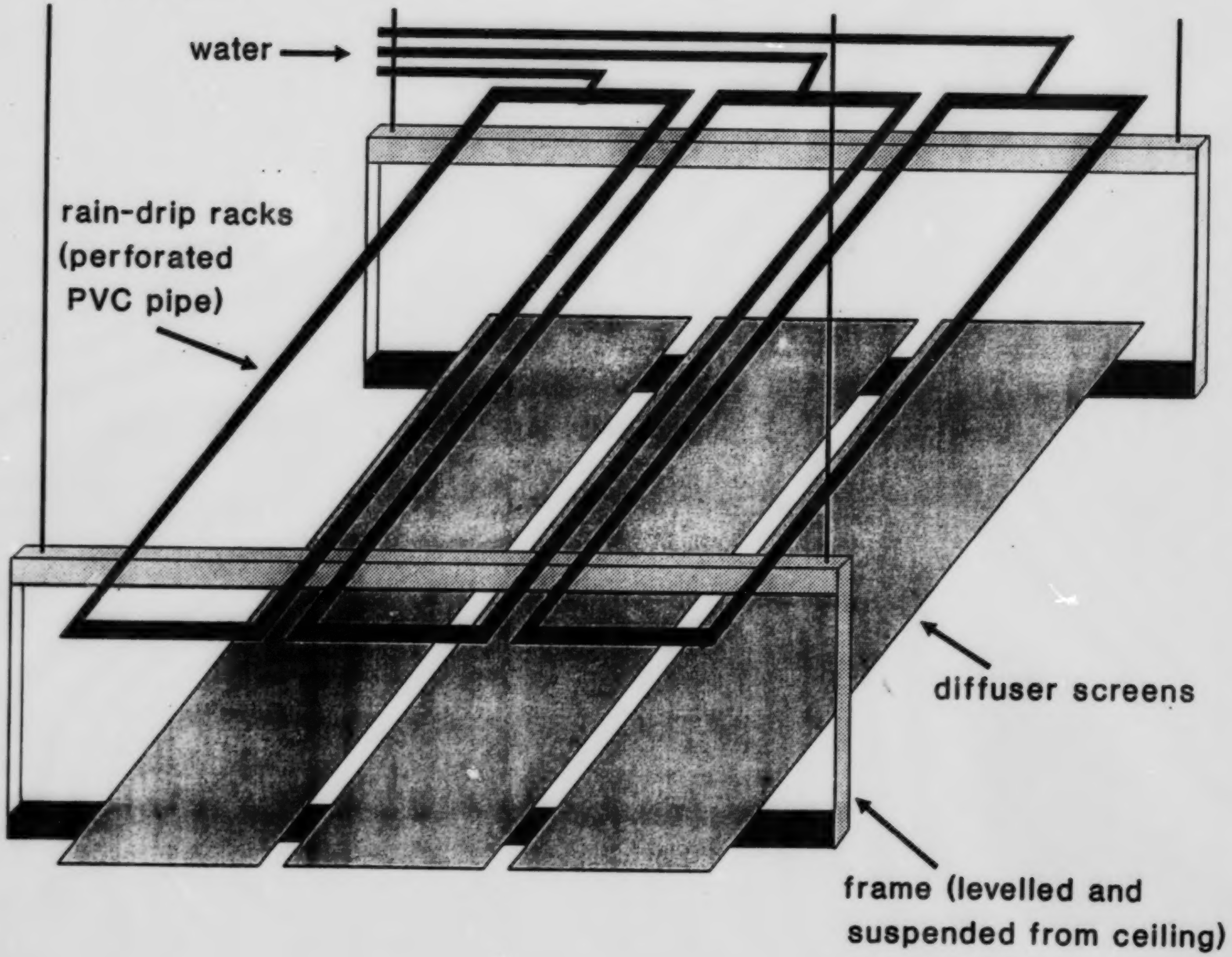

water
rain-drip rack
diffuser screen
test sediments

Figure 3. Rain-drip System


water
rain-drip racks (perforated PVC pipe)
diffuser screens
frame (levelled and suspended from ceiling)

mean annual rainfall is 435 mm; Longley and Janz, 1978) evapotranspiration exceeds precipitation during the summer, it was felt that a constant head was unrealistic. Thus the simulated rainfall was applied for short intervals, and the column allowed to drain until the next simulated event. While the total "rainfall" applied to the columns was greater than could be expected naturally for the 16 d experimental period, this simulation was closer to reality than having a constant head.

Rainfall simulation began on March 11 and continued for 2 eight-day cycles. Dechlorinated water was used. Each cycle consisted of 6 days of rainfall, followed by 2 days of drainage. To ensure uniform rain application, columns were rotated twice daily with a rainfall event in each position, therefore columns were rotated into all positions during each 6 day cycle. On the first day, rain was applied for 10 minutes at an average rate of 250 mL/minute per column. Subsequent rain events were two minutes in duration, each applied at 190 mL/minute. The initial higher rate simulates snow melt. The average air temperature during the experiment was 18°C.

2.6 Laboratory Analyses

2.6.1 Soils

Soil Chemistry Characteristics

Complete chemical analyses were performed on all replicates from each sample, except for soil physical characteristics for which pooled samples were tested. The soil analyses procedures followed Klute (1986) and Page et al. (1982) unless specified otherwise. Analyses were performed by Pacific Soil Analysts Inc. (agronomic) and ASL (Analytical Services Laboratories) of Vancouver performed the metals and hydrocarbon analysis.

Soil pH was measured from a 1:2.5 soil-water paste. Electrical conductivity was determined from a saturated soil paste extract. Total carbon was determined by combustion in a Leco furnace. Total nitrogen was measured by Kjeldahl digestion and steam distillation of the produced extract. Nitrate and ammonium were measured by steam distillation after extraction of the soil with 1 M potassium chloride. Available phosphorus and sulphate were measured by a Technicon Auto-analyzer system after extraction with 0.03 N ammonium fluoride/0.03 N sulphuric acid and 0.01 M calcium chloride respectively. Available potassium was measured by emission spectroscopy after extraction with 1 M neutral ammonium acetate.

Cation exchange capacity was determined by extracting soils with 1 M neutral ammonium acetate solution, removal of excess NH_4 with iso-propanol, and release of exchangable ammonium by treatment with acidified sodium chloride. The ammonium was measured by steam distillation. Individual exchangeable cations were measured in the ammonium acetate extract by atomic adsorption spectroscopy (AAS). Paste-extractable (soluble) cations were measured using AAS from the extract of a 1:2.5 soil/water paste.

For metals, the soils were digested using a combination of nitric and hydrochloric acids. The resulting extract was bulked to volume with deionized/distilled water. The digested portion was then analyzed using either atomic adsorption (AAS) and/or atomic emission spectrophotometry (ICP), to obtain the required detection limit for each element. These procedures were adapted from U.S. EPA Method 3050 (EPA, 1990).

For oil and grease, the samples were extracted with hexane/acetone. The extract was evaporated to dryness and the residue weighed to determine gravimetric oil and grease. For total extractable hydrocarbons (TEH), the hexane/acetone extract was analyzed by capillary column gas chromatography with flame ionization detection (EPA method 3500/8015: EPA, 19[illegible]).

Soil Physical Characteristics

All soil physical tests were performed by Soilcon Laboratories of Richmond, B.C. Parameters measured were soil moisture retention curves (Klute, 1986), saturated hydraulic conductivity (Klute and Diksen, 1986), bulk density (Blake and Hartage, 1986), and porosity (Danielson and Sutherland, 1986).

Nematode Bioassays

Soil bioassays were performed using the nematode (*Panagrellus redivivus*) according to the procedures outlined by Samoiloff (1990). The bioassays were conducted by BioQuest International at their Winnipeg laboratories during March 1992. For each sample, three water extracts (50%, 10% and 1%) and two methanol extracts (3% and 1%), were prepared and tested for toxicity. Water extracts were made by preparing 1:1 (v/v) mixtures of soils and ultrapure water and collecting the liquid phase after 24 hours. Methanol extracts were made by preparing 1:1 (v/v) mixtures of soil and methanol and extracting the liquid phase after 24 hours. The soil-water and soil-methanol mixtures were agitated during the 24 h extraction period. The two extractions were used since the methanol extract would likely contain more non-polar contaminants and fewer polar contaminants than would aqueous extracts.

Hyalella azteca Toxicity Test

Sediment toxicity tests using the juvenile freshwater amphipod (*Hyalella azteca*) were conducted using a test procedure based on ASTM (1991). The tests were conducted in a constant environment room at 24 ± 1° C under a 16:8 h light:dark photoperiod. Juvenile *H. azteca* were obtained from in-house cultures. Acute lethality testing of the whole fresh (unfrozen) sediments involved a 10-d exposure of juvenile organisms (< 10-d old) to the test sediment. Negative controls consisted of clean silica sand in jars covered with clean plastic lids. Control jars were aerated overnight prior to test initiation to allow the sediments to settle and allow any contaminants in the sediments to come to equilibrium in the water. Three field replicates were tested per treatment. The control consisted of five replicates with an additional sixth jar, without any amphipods, serving as a reference for daily measurement of water chemistry (pH, dissolved oxygen, conductivity and temperature). Water quality for the test sediments was measured in field replicate A. Hardness of control water was measured on Day 0 and Day 10.

The test was terminated after 10 d when the sediments were sieved and live and dead amphipods were removed and counted. Amphipods were considered dead when there was no response to physical stimulation. Missing amphipods were assumed to have died and decomposed prior to the termination of the test. Surviving *H. azteca* from each replicate were placed in pre-weighed aluminum weighing pans and dried at 60° C for 24 h. The pans were then weighed to obtain the total dry weight for each replicate.

CO_2 Evolution

Microbial activity, as indicated by respiration, was assessed by measuring CO_2 evolution from 20g of sample over a 28 d period at 7 d intervals in biometer flasks (Sobolewski, 1992). Using an air pump, air was blown into the column of the apparatus during the titration process for about 15 minutes per sample. A 0.1 N HCl solution was prepared and added to the titration burette. A KOH solution, in the column from the previous week, was removed to a 50 mL beaker. The column was then rinsed with CO_2-free water for removal of any residual KOH, and 10 mL of this water was added to the 50 mL beaker. The solution was stirred on a hot plate while adding phenolphthalein until a strong pink colour was achieved (3-5 drops). One milliliter of BaCl solution was added (to form a white precipitate), then this solution was titrated with 0.1 N HCl solution until the solution in the beaker turned colourless. The initial and final volumes of the acid were recorded and the CO_2 evolved per sample was calculated.

Nitrifying Potential

The nitrifying potential of the soils was assessed following the method described by Schmidt and Belser (1982). Soils were allowed to air dry overnight at 20° C in acid-washed pyrex baking dishes. The nitrifying potential tests were initiated the following day. Baseline samples were collected prior to test initation and stored at 4° C. Four 100 gram samples from each column were weighed into clean acid and acetone washed beakers, two labelled control and two labelled amended. Amended beakers were treated with 2 mL of 25 ppt (g/L) ammonium sulphate [$(NH_4)_2SO_4$] while controls were not treated. Samples amended with ammonium sulphate were reweighed so that moisture losses could be determined. All beakers were then individually covered with aluminum foil, placed into a cardboard box with a max-min thermometer, and incubated for 21 days. Samples were weighed weekly, and moisture losses restored by the addition of distilled water. Following the incubation period, nitrate (NO_3-N) concentrations were determined for each sample. The "nitrifying potential" was calculated by subtracting the average initial from average final nitrate concentrations. The amount of nitrate formed during incubation would depend on the extent of the bacterial nitrifying population. Samples amended with NH_4^+, would have excess nitrifiable substrate, and the nitrifying microbe population would be expected to increase until limited by other factors.

2.6.2 Leachate Water

Leachate Chemistry

Analyses for physical tests, nutrients and metals were carried out following standard procedures (APHA, 1989). Metal analysis procedures involved a variety of instrumental analyses including atomic emission spectrophotometry (ICP) and atomic adsorption spectrophotometry (AAS) to obtain the detection limit required for each element.

Microtox™

Leachate collected during the acclimation period and during each rainfall cycle were analyzed for toxicity by Beak Consultants (Richmond, B.C.) using Microtox™. Replicates were composited for each treatment to obtain sufficient leachate for testing. Microtox™ testing measures toxicity based on the reduction of light emission from a bioluminescent bacteria in the presence or absence of a toxicant. Tests were performed on the Beckman Model 2055 Microtox Toxicity Analyzer System. The test bacteria are exposed to different concentrations of a sample and any loss of emitted light over time is recorded. Leachates were tested at 22.75, 45.4, and 90.0 % (vol/vol) and light levels were measured at 5, 15, and either 20, 25, or 30 minutes after exposure of bacteria to the sample. The EC_{50} is the concentration of the sample which results in a 50% reduction in light emission.

Daphnia magna

One (1) modified 21-d partial life-cycle test, using *Daphnia magna*, was performed using methods described by ASTM (1989) and the Alberta Environmental Centre (1990). Juvenile daphnids, or neonates, were removed from an in-house culture for use in testing. One concentration [50% (vol/vol)] was tested for each sample. The bioassay containers were 150 ml glass beakers with a test solution volume of 100 mL. The test was modified by using only one replicate for each test solution (due to limited sample volumes) and five controls, each containing a single daphnid. Test solutions were changed Mondays, Wednesdays and Fridays. On solution replacement days, temperature, dissolved oxygen, pH, and conductivity were measured in the new solutions, and dissolved oxygen was measured in the old solution. Offspring and moults were counted and then removed from the test containers when the test solutions were renewed. Each test beaker received 1 mL of YCTF-algae food mixture three times weekly.

The test was allowed to proceed for 21 days. The measured endpoints were survival and total reproduction. For the test to be considered valid, mean mortality in the negative control could not exceed 80%.

3.0 RESULTS

3.1 Soils

3.1.1 Hydrocarbons and Metals

Levels of hydrocarbons and metals are summarized in Table 1 and raw data are presented in Appendix A. For Treatments 1, 2, 3, and 4, mean oil and grease contents were 0.07%, 0.1%, 2.2%, and 5.6% respectively (by weight). Mean total extractable hydrocarbon (TEH) contents were 0.02%, 0.04%, 0.9%, and 1.8% respectively. Differences between treatments were significant at $P \leq 0.01$ for both oil and grease and TEH, based on a one-way analysis of variance.

Table 1. **Summary of soil analysis for hydrocarbon and metals.**

Parameter	Treatment Mean[1] (n=3)			
	T1	T2	T3	T4
Extractables				
Oil and Grease	650 (130)	950 (118)	22100 (361)	55533 (19133)
TEH	165 (119)	405 (37)	8673 (3607)	17663 (7592)
Metals				
Arsenic	0.70 (0.05)	0.71 (0.04)	1.24 (0.11)	1.86 (0.34)
Barium	5.5 (0.3)	17.8 (0.5)	24.1 (0.4)	35.6 (3.3)
Cadmium	NA[2]	NA	NA	NA
Chromium	NA	1.5 (0.9)	8.3 (0.06)	13.7 (1.3)
Cobalt	NA	NA	3.5 (0.1)	5.2 (1.0)
Copper	0.7 (0.4)	2.2 (0.3)	3.5 (0.2)	4.8 (1.2)
Lead	NA	NA	NA	NA
Mercury	0.003 (0.001)	0.009 (0.001)	0.015 (0.003)	0.015 (0.003)
Molybdenum	NA	NA	NA	NA
Nickel	NA	2.7 (0.5)	11.5 (0.4)	20.7 (4.8)
Selenium	NA	NA	NA	0.15 (0.03)
Silver	NA	NA	NA	NA
Tin	NA	NA	NA	NA
Zinc	4.7 (0.5)	25.2 (7.6)	17.7 (1.1)	21.4 (3.3)

All results in mg/L dry wt. unless indicated otherwise.

[1] The standard deviation appears in brackets following each mean.
When laboratory duplicates were tested for QA/QC, the average was used for statistical purposes.

[2] NA indicates results below detection limits.

As previously observed in field soils with similar proportions of hydrocarbons (Hamilton, 1992), metal content increased with increasing fine tails content. This indicates that fine tails are the main source of metals in the amended soils, with the exception of zinc. Zinc levels increased with addition of peat and did not appear to increase with hydrocarbon content. Of the metals analyzed, Cu, Co, Mo and Zn are essential nutrient elements for plant growth. Levels for these elements were within a suggested range sufficient for plant growth (Brady, 1990). Five metals, Cd, Pb, Mo, Ag, and Sn, were not detected (i.e., levels were below detection limit) in any treatment. Concentrations of metals in all treatments are in the common range for soils reported by Allaway (1970), and are below the range typically found in sewage sludge (Furr et al., 1976). Most metals are relatively unavailable to plants at pH > 6.5 (Brady, 1984). Soil pH for all treatments in this study were above 6.5.

3.1.2 Soil Chemical and Physical Properties

Soil chemical and physical properties are summarized in Table 2.

Soil Reaction

All soil treatments were neutral to slightly alkaline. Soil pH increased from 6.9 to a maximum of 7.8 in Treatment 4 with the addition of the peat and fine tails. This increase may be attributed to the presence of basic cations (Mg, Ca, Na, K) in the peat, as well as the alkalinity of the fine tails which was previously determined to be 8.2 to 9.2 (Rowell, 1983).

Total Carbon

Total carbon analysis by the Leco dry combustion furnace includes hydrocarbons from fine tails additions as well as the peat which was included in Treatments 2, 3, and 4. In Treatments 3 and 4, bitumen was present on the soil surface after mixing. As expected, total carbon was highest in Treatment 4 (17.9 %) and lowest in Treatment 1 (0.23%). Mean total carbon was unexpectedly lower in Treatment 3 than in Treatment 2. Two possible explanations are: 1) the sample used for combustion may not have been completely homogenized, or 2) analytical error.

Table 2. Summary of Soil Physical and Chemical Properties.

Parameter	Treatment Mean[1] (n=3) T1	T2	T3	T4
Physical and Chemical Properties				
pH	6.9 (0.2)	7.4 (0.05)	7.8 (0.0)	7.7 (0.05)
Total Carbon (%)	0.23 (0.02)	7.5 (1.0)	4.7 (0.05)	17.9 (1.1)
CEC (meq/100g)	1.90 (0.61)	18.4 (1.8)	10.0 (0.5)	23.1 (0.5)
Electrical Conductivity (mmhos/cm)	0.49 (0.04)	1.94 (0.33)	1.67 (0.08)	1.13 (0.19)
Moisture (%)	18.2 (0.4)	27.7 (3.4)	27.3 (1.1)	40.2 (2.9)
Available Nutrients				
Phosphorus (mg/kg)	27 (3)	40 (2)	24 (7)	19 (5)
Sulphur (mg/kg)	5 (1)	153 (41)	81 (6)	50 (1)
Ammonium (mg/kg)[2]	12.5 (1.4) a	11.5 (1.4) a	19.0 (1.9) b	49 (9) c
Nitrate (mg/kg)[2]	3.6 (0.6) a	30 (15) b	1.9 (0.5) c	2.8 (0.6) a
Total Nitrogen (%)[2]	0.01 (0.00) a	0.25 (0.06) b	0.14 (0.00) c	0.24 (0.01) b
Exchangeable Cations				
Potassium (meq/100g)	0.42 (0.20)	0.13 (0.02)	0.30 (0.04)	0.48 (0.02)
Calcium (meq/100g)	2.03 (0.33)	27.0 (0.7)	15.3 (0.5)	10.3 (0.9)
Magnesium (meq/100g)	0.40 (0.04)	1.73 (0.10)	1.38 (0.06)	2.25 (0.18)
Sodium (meq/100g)	0.12 (0.09)	0.05 (0.01)	0.73 (0.02)	2.10 (0.11)

1. The standard deviation appears in brackets following each mean. When laboratory duplicates were tested for QA/QC, the average was used for statistical purposes.
2. Means in the same row with the same letter are not significantly different at P ≤ 0.05.

Total N and C:N Ratio

Mean total N for Treatments 1 through 4 was 0.01%, 0.25%, 0.14%, and 0.24%. As was the case with total carbon, Treatment 3 was unexpectedly lower than Treatment 2. Levels of total N were within the normal range of 0.02-0.5% for temperate soils (Brady,1990). The carbon:nitrogen (C:N) ratios for all treatments were relatively high; 23, 30, 34, and 76 respectively for Treatments 1, 2, 3, and 4. The common range of C:N ratios found in arable soils is 8:1 to 15:1 (Brady, 1990). Wider ratios generally indicate slow organic matter decomposition rates due to competition among microorganisms for available nutrients.

Available Nutrients

Nitrate levels were considerably lower in the treatments containing fine tails than in Treatment 2, despite similar levels of total N. There are two possible explanations: 1) nitrification is inhibited by the some compounds present in fine tails; or 2) microbial hydrocarbon degraders rapidly utilize the nitrate as it is made available. In the presence of fresh hydrocarbons, a rise in the population of hydrocarbon degrading bacteria raises the demand for nitrogen (Bartha, 1986), usually a short term effect. However, inhibition effects may be long-lasting (Pritchard and Bourquin, 1985). Ammonium levels were highest for Treatments 3 and 4 which supports the idea that nitrification is inhibited by fine tails.

Levels of available P ranged from 19-40 mg/kg for all treatments. Soil P is usually associated with the inorganic component of soil and may be relatively unavailable. At the near neutral pH of these soils, the phosphate is in the form of soluble Ca and Mg phosphates (Bohn et al., 1985). Unlike P, soil S is associated with the organic components of soil. Both peat and fine tails have been shown to contain higher SO_4^{2-} levels (Rowell, 1983) which explains the higher levels in Treatments 2, 3, and 4.

Cation Exchange Capacity and Exchangeable Cations

The cation exchange capacity was substantially higher in treatments with peat and fine tails due to higher levels of clay and organic matter. The percentage base saturation, defined by the equation;

$$\%\text{ base saturation} = \frac{\text{exchangeable bases (Ca, Mg, K, Na)}}{\text{cation exchange capacity}}$$

is 200.0%, 157.1%, 177.4%, and 65.6% for Treatments 1, 2, 3, and 4. Base saturation greater that 100% may be due to: 1) high levels of soluble calcium salts associated with the peat, or 2) the solution used to extract exchangeable bases may also solubilize non-exchangeable salts. Calcium was the dominant exchangeable cation occupying the majority of the exchange complex, followed by magnesium, potassium and sodium. Sodicity or excess sodium and salinity does not appear to be a problem. Nutrient imbalances caused by the relatively high calcium levels may lead to apparent deficiencies of K and Mg for some plants in the field.

3.2 Soil Bioassays

Soil bioassays were performed on the soils prior to leaching. The two species used were the freshwater amphipod (*Hyalella azteca*) and the soil nematode (*Panagrellus redivivus*). Complete reports are contained in Appendix B.

Hyalella azteca

Survival in the control sediment was significantly greater ($P<0.05$) than for all treatments. No animals survived for the duration of the test in Treatments 3 or 4, and only 10% survived in Treatment 1 and 7% in Treatment 2. *H. azteca* appear to be very sensitive to any toxicants which are present. Observations during testing indicate that low survival in Treatments 3 and 4 may be due to a hydrocarbon coating on the animals. *H. azteca* have been shown to be extremely sensitive to metals and low pH (Mackie, 1989). The source of the toxicity in Treatment 1 and 2 soils is not known. It is possible that the relatively low hydrocarbon contents in the T1 and T2 soils was toxic to this species.

Panagrellus redivivus

Samples from each treatment exhibit a range of toxic effects, but differences in means are not significant ($P \leq 0.05$) among treatments with increasing fine tails, except for the 10% water extraction. Data are summarized in Table 3. All samples showed toxic effects for both water and methanol extractants except for Treatment 1 which did not show any toxicity in methanol.

The widest range of toxic effects occurred using the 10% water extractant. Summary statistics are shown in Table 4. Treatments 3 and 4 were significantly different ($P \leq 0.05$) from Treatments 1 and 2 for all health indicators, except for survival where only T4 was significantly different. The differences in toxicity appear to indicate a greater occurrence of toxicity in treatments with fine tails (i.e., T3 and T4).

Table 3. Summary of nematode (*Panagrellus redivivus*) bioassay test results. Points assigned by qualitative toxicity criteria. Table is a rearranged version of Nematode Bioassay Results in Appendix B.

0 points	no detected effect
1 point	marginal stimulation
2 points	slight toxicity
3 points	some toxicity
4 points	moderate toxicity
5 points	high toxicity
6 points	extreme toxicity

Treatment	Replicate	3% methanol	1% methanol	50% water	10% water	1% water
1	A	0	0	5	4	0
	B	0	0	5	4	0
	C	0	0	5	0	0
2	A	0	0	5	3	0
	B	0	0	5	2	0
	C	1	0	5	3	1
3	A	4	0	6	5	0
	B	4	2	6	4	0
	C	4	0	6	4	0
4	A	4	0	6	5	0
	B	0	0	6	5	2
	C	0	0	6	5	0

Table 4. Summary statistics for nematode testing with 10 % water extract.

Indicator	Treatment	Mean[1]	SD	CV (%)	ANOVA	
					F	P
Fitness	1	91.7 a	7.6	8	21.0	0.001
	2	90.0 a	1.7	2		
	3	68.0 b	11.8	17		
	4	28.0 c	17.3	62		
Survival	1	94.0 a	5.6	6	8.3	0.008
	2	94.0 a	2.6	3		
	3	87.0 a	12.3	14		
	4	42.7 b	26.3	62		
Growth	1	87.3 a	11.9	14	28.5	0.001
	2	91.0 a	6.6	7		
	3	56.0 b	17.3	31		
	4	12.3 c	8.5	69		
Maturation	1	93.0 a	10.6	11	132.3	0.001
	2	74.0 b	6.0	8		
	3	15.7 c	5.9	37		
	4	0 d	0	-		

[1] Within each indicator, means with the same letter are not significantly different at $P \leq 0.05$ based on a Mann-Whitney test.

3.3 Microbiology

CO_2 Evolution

Figure 4 shows the cumulative evolution of carbon dioxide over 28 days for the four treatments. The data suggest that the hydrocarbons are degraded since these compounds are the principal carbon substrate in T3 and T4. After 28 days, the differences between treatments in mean total CO_2 evolved was significant at $P \leq 0.01$, based on an one-way analysis of variance. With the T3 and T4 soils, there was a flush of CO_2 in the first week, as indicated by the slope of the curve. The rate of CO_2 evolution then slowed down through week 3, before increasing again in the last week.

Nitrifying Potential

Table 5 and Figure 5 show the differences between treatments in the amount of nitrate-N present in the soils. In both Treatment 1 and 2, a portion of the added ammonium-N has been converted to nitrate. In Treatments 3 and 4, nitrification has been completely inhibited. The very large differences between T2 (sand and muskeg) and T3 and T4 suggests that certain hydrocarbon compounds are toxic to nitrifying bacteria. The fine tails amended soils have greater amounts of ammonium-N than T2 even before the $(NH_4)_2SO_4$ was added (Table 2), but it is not nitrified. As the T1 and T2 results indicate, nitrifying bacteria were present in the sand/muskeg mixtures.

3.4 Rainfall and Infiltration

The simulated rainfall was applied in discreet "events" over two six-day periods to imitate natural cycles of rainfall and soil drainage (cf. Section 2). In the Fort McMurray area, which has a mean annual precipitation of 435 mm with a summer maximum (Figure 6), the volume of water that actually moves through the soil profile to groundwater in any given year is probably small. The period of maximum precipitation also corresponds to the period of maximum potential evapotranspiration, and there is a mean summer moisture deficit (Figure 7). On an annual basis, the mean potential evapotranspiration is estimated to be 386 mm by the Thornthwaite equation (Kirkby et al., 1987). Thus the net water balance, assuming no runoff, is 49 mm. For these reasons, the simulated rainfall was applied in relatively spare amounts.

Figure 4. Cumulative Carbon Dioxide Production

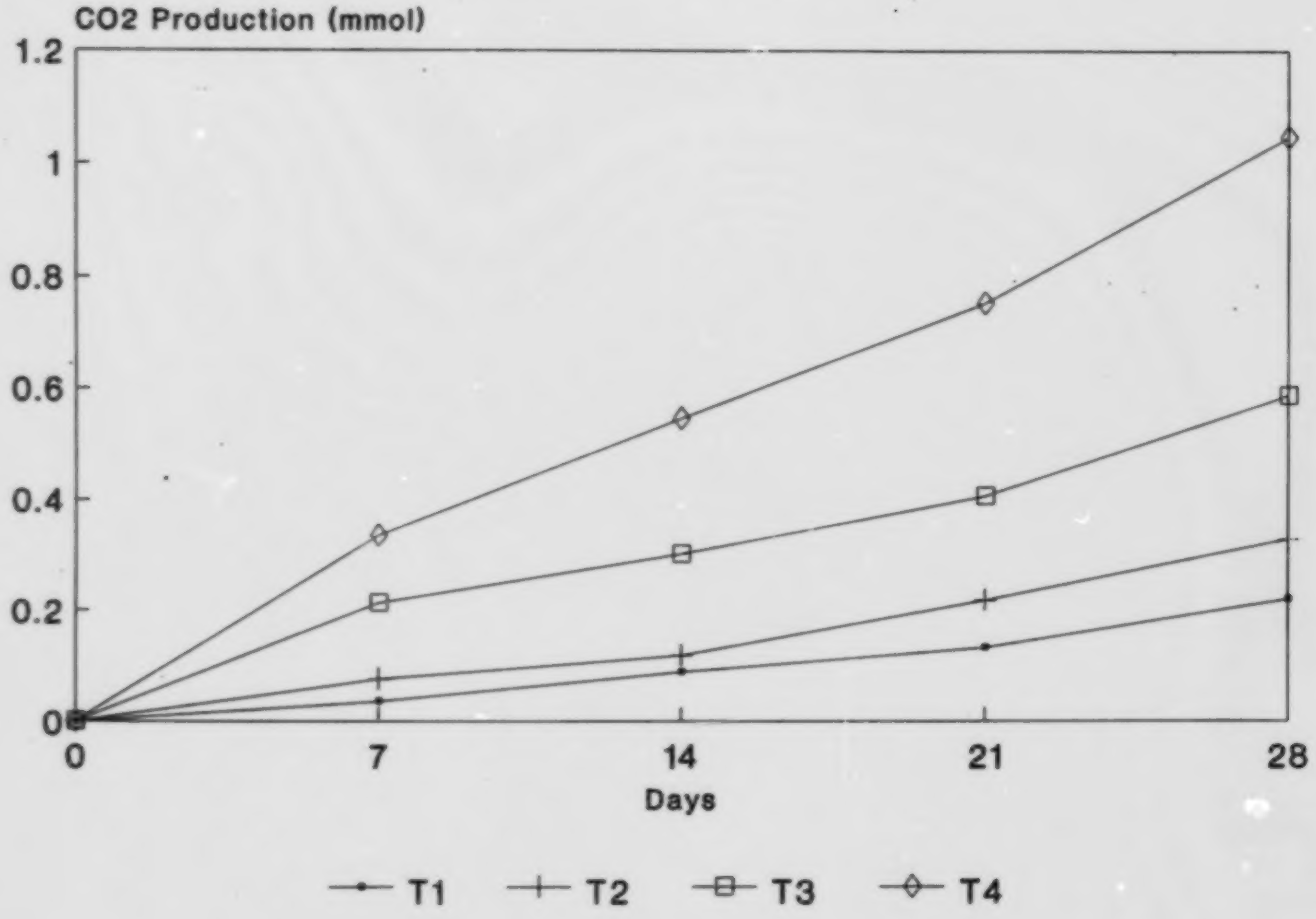


Table 5. **Nitrifying Potential of Soil.**

Sample	Replicate	Levels of NO_3^-–N (ppm)					Nitrifying Potential
		Background*	Control**	Amended***	Mean Control	Mean Amended	
T1	A	5.3	11.7	30.0	10.9	27.0	21.7
	B		10.0	24.0			
T2	A	27.3	26.3	94.3	26.6	97.2	69.9
	B		26.9	100.0			
T3	A	2.0	2.9	2.3	2.8	2.2	0.2
	B		2.6	2.0			
T4	A	1.4	1.1	1.1	1.0	1.0	−0.4
	B		0.9	0.9			

* Not enough sample was present for more than one background analysis.

** No ammonium sulphate added.

*** Ammonium sulphate added.

Figure 5. **Nitrifying Potential**

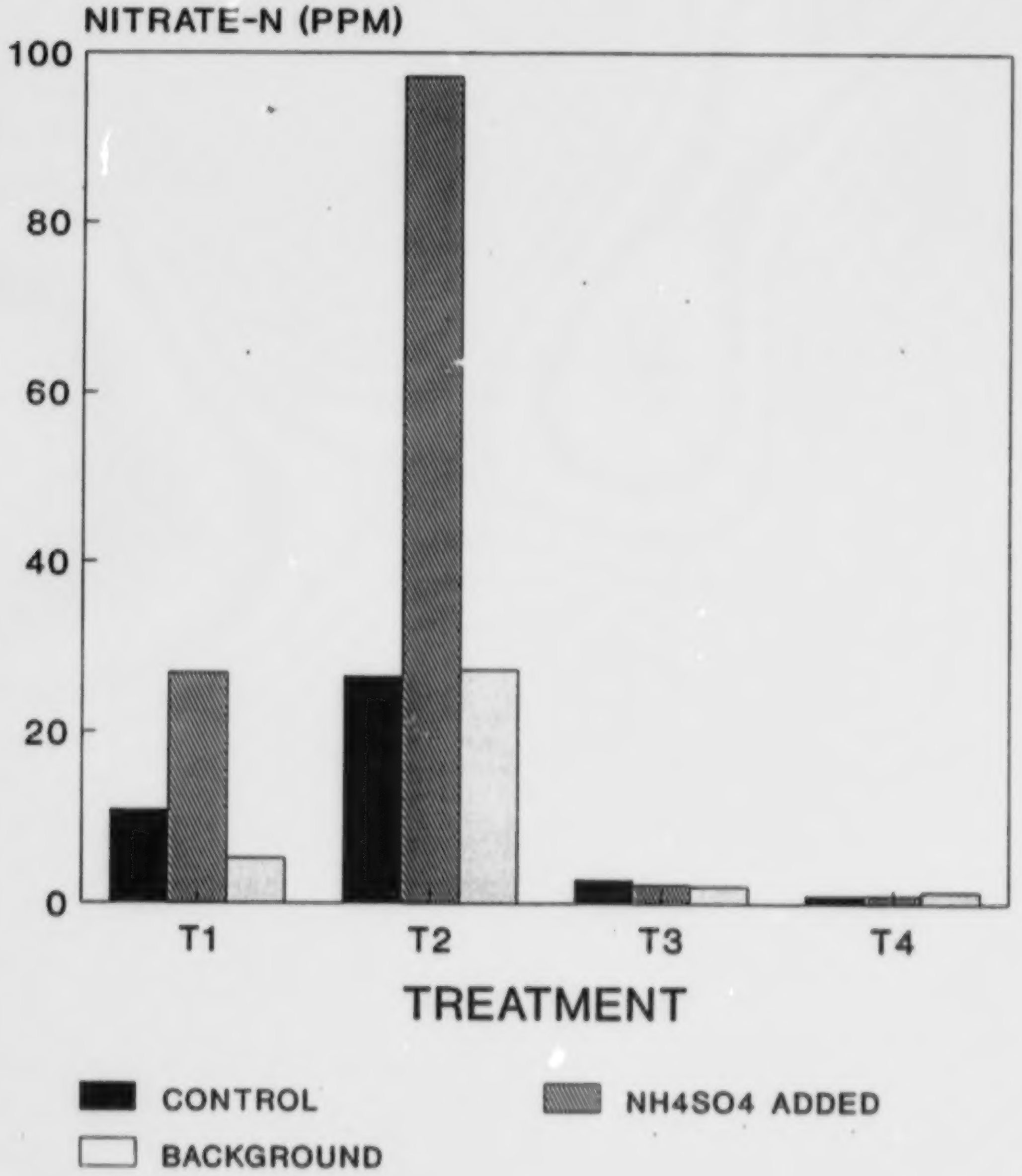
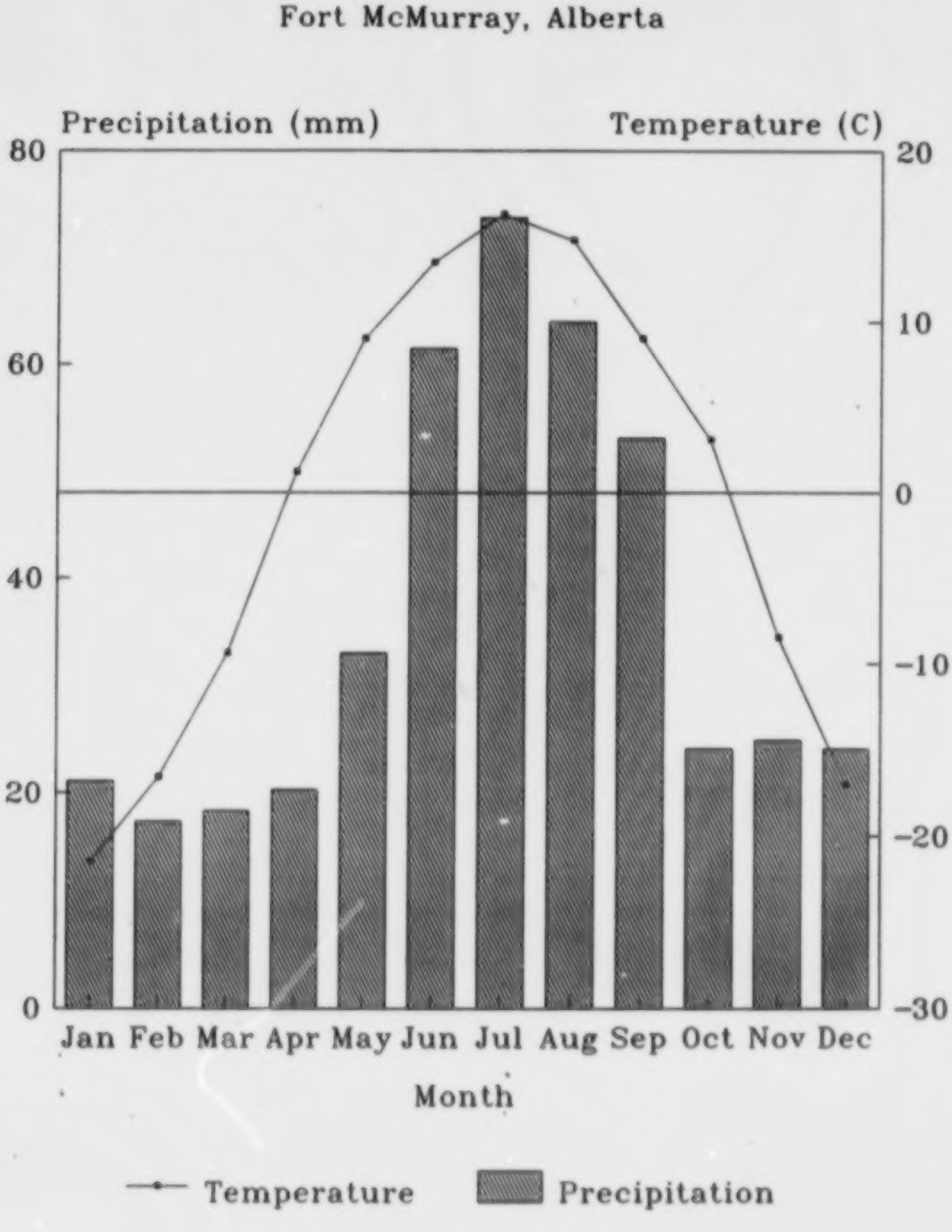
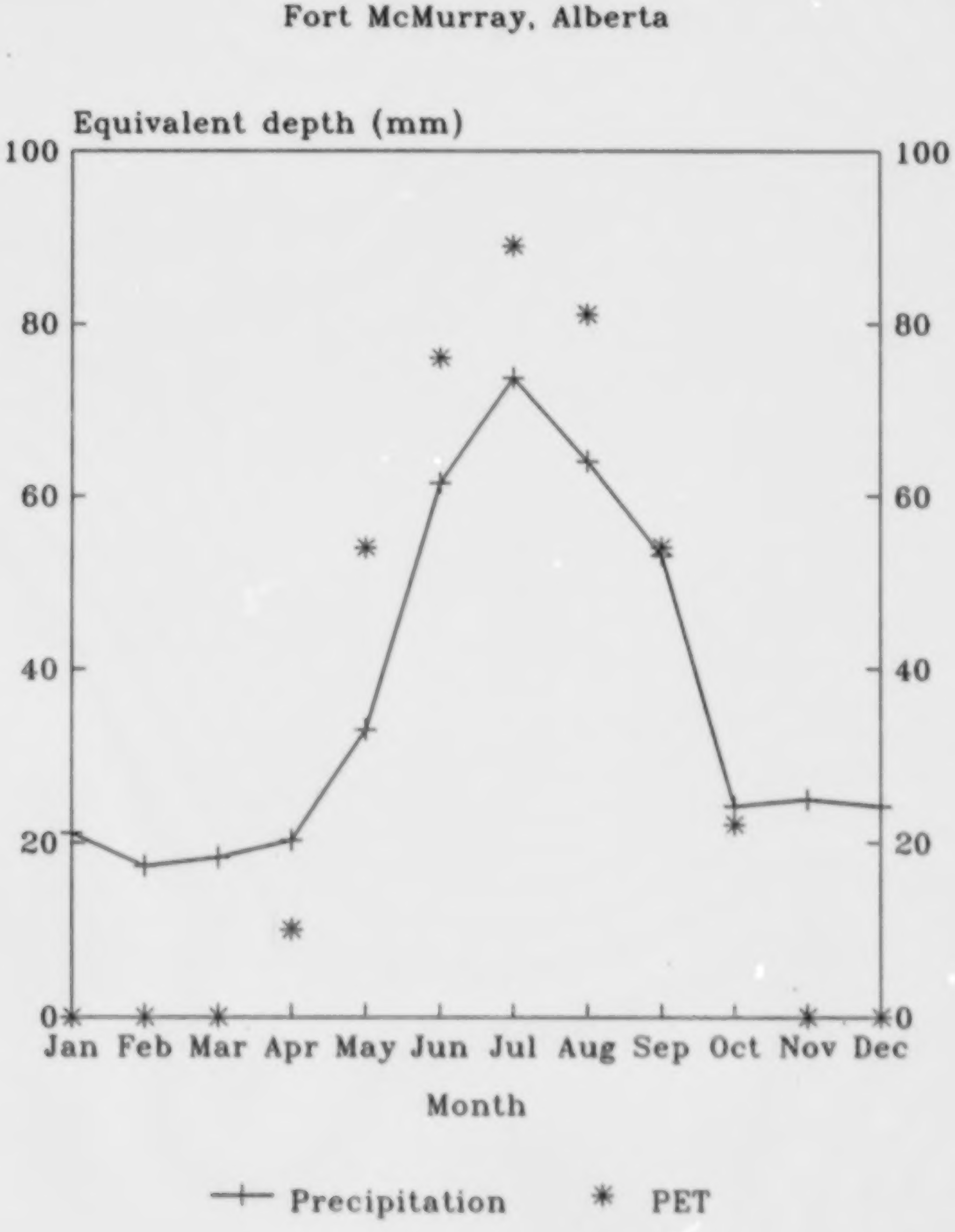


Figure 6. **Temperature & Precipitation**



Source: Longley and Janz, 1978.

Figure 7. **Precipitation & Potential Evapotranspiration (PET)**



Source: Longley and Janz, 1978.

Figure 8 shows the daily and cumulative amounts of rainfall applied to the columns for the two six-day cycles. The mean (n=3) volume of leachate collected from each of the four treatment is shown in Figure 9. The effect of the bitumen in the T3 and T4 mixtures is clear. Both T1 and T2 drained to field capacity relatively quickly following the cessation of the rain, whereas ponding formed on the soil surface with T3 and T4 after a few days. This head was retained for the remainder of the experiment and by day 13 it was about 10-12 cm deep on both T3 and T4. The complete rainfall and leaching volume data set is listed in Appendix A.

The mixing of fine tails with the other soil materials reduced the water retention at pressure potentials between -5 and -100 kPa (Figure 10) when compared against Treatment 2. T4 (high fine tails) retained less water than T1 (tailings sand). This is consistent with the pattern observed by Rasiah et al. (1990) for the application of a heavy fuel oil to two clay loams. Evidently, the oil had succeeded water in competition for pore space. Treatment 2 exhibited the highest water retention.

The saturated hydraulic conductivity (K_{sat}) was much lower on the soils with fine tails, as was expected from the ponding which occurred during the rain events (Table 6). The mean K_{sat} for Treatments 1 and 2 was 14.9 and 21.1 cm/h respectively, versus 0.5 and 1.2 cm/h for T3 and T4. The higher value for T2 over T1 are due to a higher mean porosity. While the porosity values for T3 and T4 are relatively high at about 0.50, the pores are clogged with bitumen which clearly limits the downward movement of water. These data, when combined with water balance data for Fort McMurray, indicate that very little leachate may be expected to move past the upper soil layers to groundwater for the first few years after application. Surface ponding and subsequent evaporation is more probable.

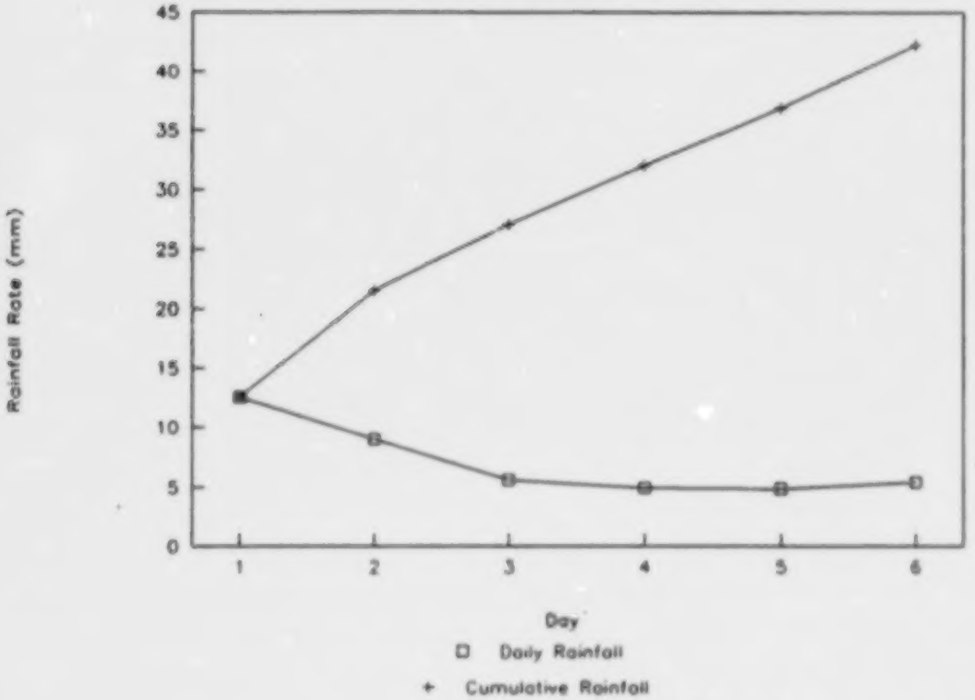
Table 6. Soil Physical Properties

Treatment	Saturated Hydraulic Conductivity (cm/h)	Bulk Density (g/cm^3)	Porosity (v/v)
T1	14.9 (15.7)	1.73 (0.02)	0.34 (0.01)
T2	21.1 (7.4)	0.90 (0.06)	0.61 (0.02)
T3	0.5 (0.5)	1.17 (0.02)	0.51 (0.01)
T4	1.2 (0.8)	1.19 (0.02)	0.50 (0.01)

n=3. Standard deviation in brackets.

Figure 8. **Daily Rainfall Rates (mm)**

Daily Rainfall Rate (mm): Days 1-6



Daily Rainfall Rate (mm): Days 8-13

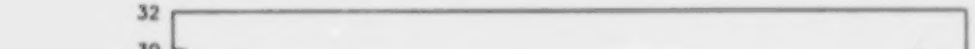
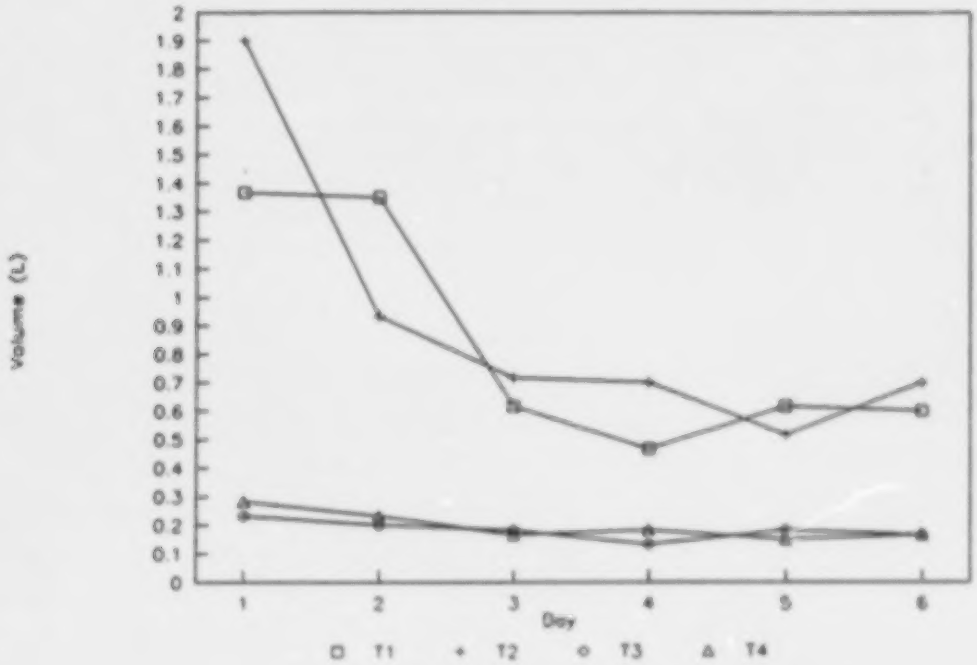


Figure 9. **Leachate Volumes Collected**

Leachate Volume Collected: Days 1-6



Leachate Volume Collected: Days 8-13

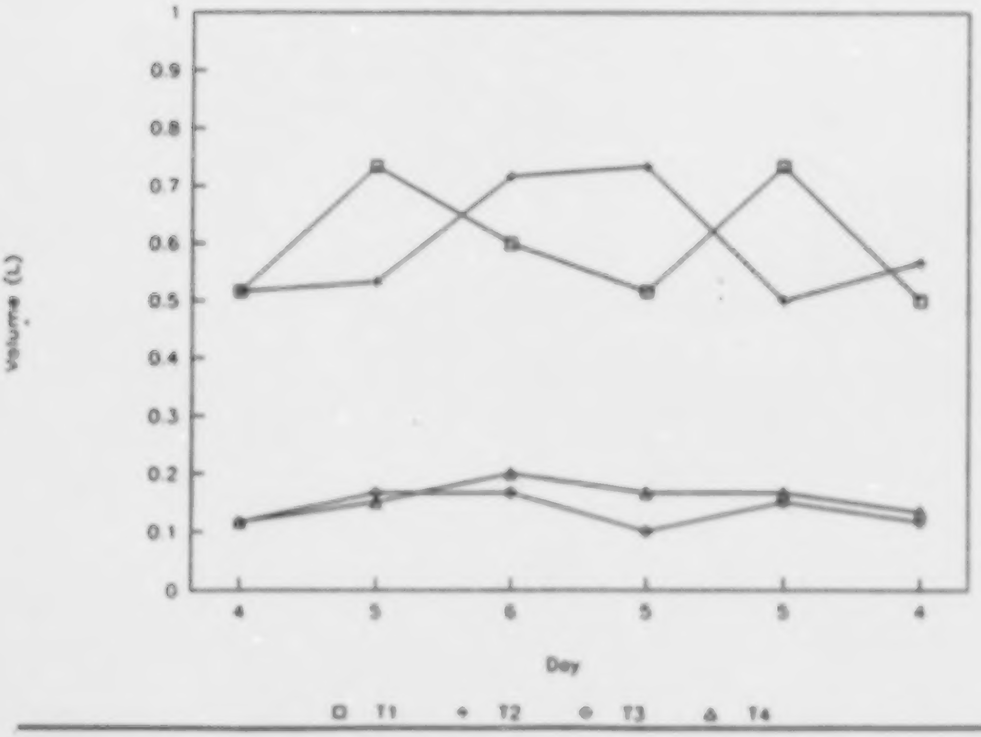
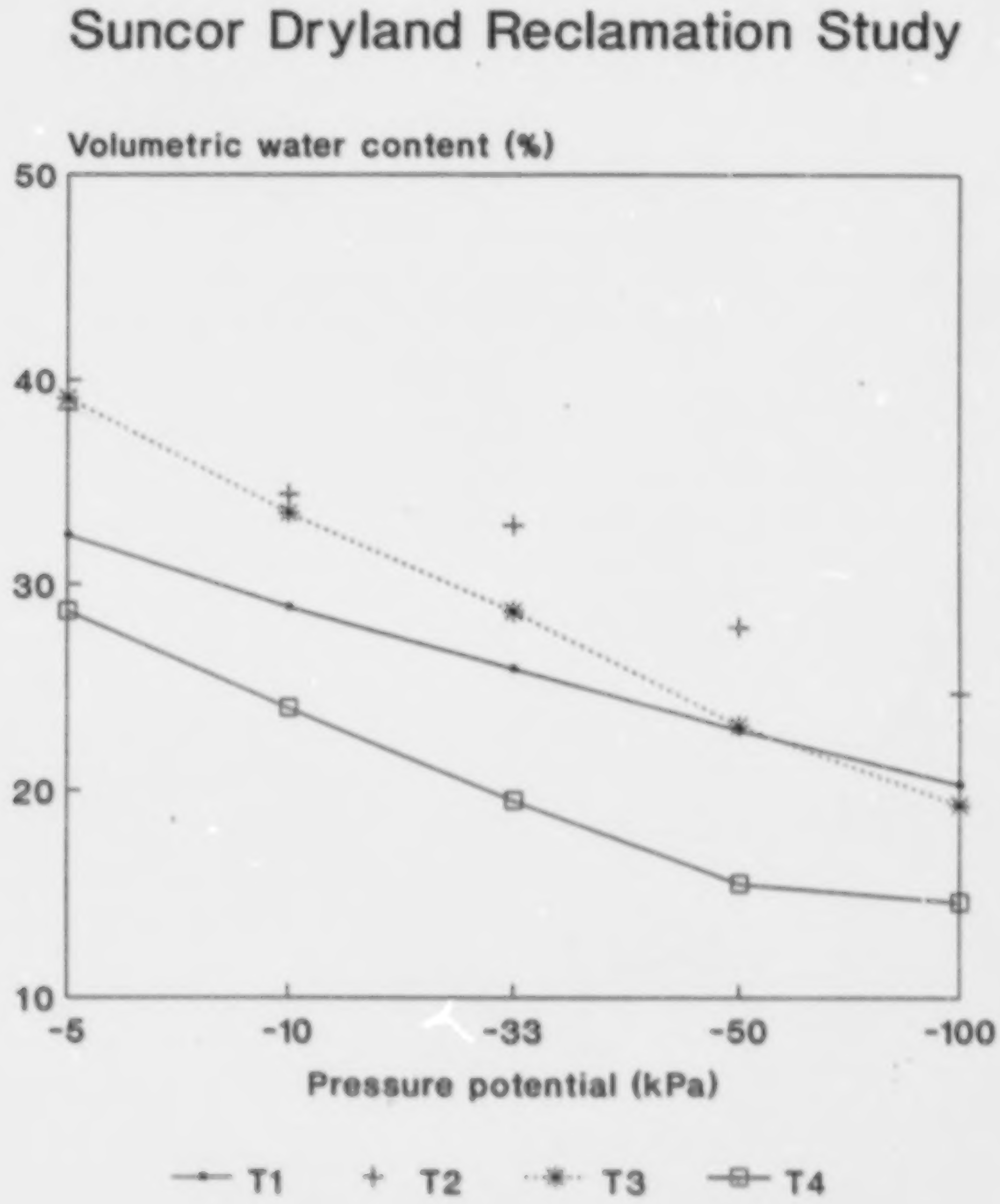


Figure 10. Water Retention Curves.



Each point is the mean of 3 samples

3.5 Leachate Water Chemistry

Levels of all water chemistry parameters declined during days 8-13 as compared to days 1-6. Although no measurements were made, visual observations of leachate indicated that the leachate collected in Treatments 2, 3, and 4 were less turbid than Treatment 1. Turbidity declined in all treatments during days 8-13. Easily leached particulates and compounds are removed during the initial flush of water leaving the more strongly adsorbed particulates. Conductivity decreased as leaching progressed (Figure 11). Leachate pH remained fairly constant throughout the experiment fluctuating between pH 7.1 to 8.3 (Figure 11). Dashed lines on the figure showing leachate pH indicate the range suggested for freshwater aquatic life (CCREM, 1987). The pH of our rainwater ranged from 7.0 - 7.3.

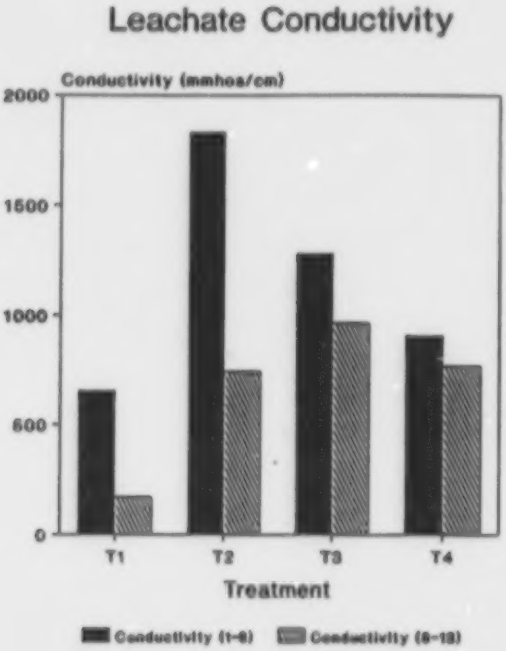
Levels of some key plant required nutrients are shown in Figure 12. As expected, levels of nitrate and ammonium, both soluble and mobile in the soil, decreased as leaching progressed. Levels of nitrate were highest in Treatments 1 and 2 during days 1-6. Ammonium levels decreased as leaching progressed but remained high in Treatments 3 and 4. Phosphorus levels increased in T2, T3, and T4 as leaching progressed. Phosphorus is less mobile in the soil, compared with nitrogen compounds.

3.5.1 Hydrocarbons and Metals

Data for hydrocarbons and metals are summarized in Appendix A. Hydrocarbon levels in all leachates declined as rainfall progressed (Figure 13). During days 1-6, oil and grease levels were highest in Treatment 1 and lowest in Treatment 2. After flushing during days 1-6, oil and grease declined below detection limits in T1, T2, and T3 but increased in T4. Leachate hydrocarbon levels were significantly ($P \leq 0.05$) lower than levels in the soil samples.

Metal content in the leachate decreased as leaching progressed. Levels of metals were not particularly high, the majority below 1 mg/L. Twelve metals were not detected in any leachate. The declining trend is shown for three metals in Figure 14. Iron and aluminum levels were highest in Treatments 1 and 4 during both leaching periods. Zinc levels for all treatments were all below 1 mg/L. Dashed lines on these graphs show levels recommended for freshwater aquatic life in the Canadian Water Quality Manual (CCREM, 1987). Metals found consistently in the highest levels were calcium, magnesium, potassium, and sodium. These metals are normally leached from cation exchange sites to the largest extent because they are held weakly by the soil complex and are more soluble than others in water (Figure 15).

Figure 11. Leachate Conductivity and pH



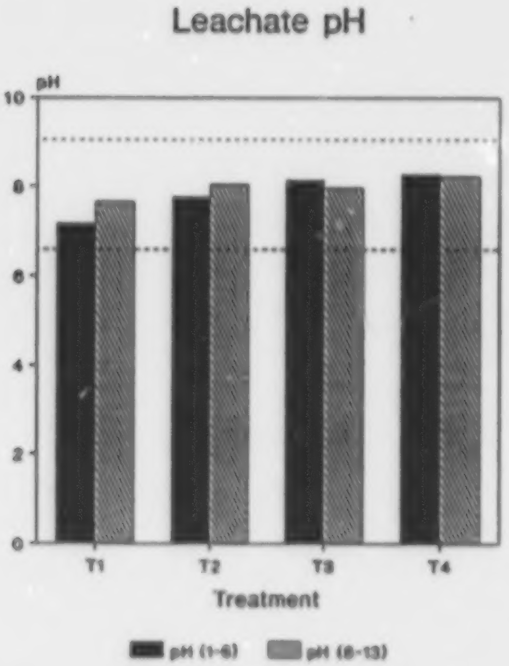


Figure 12. Leachate Nitrate, Phosphorus and Ammonium

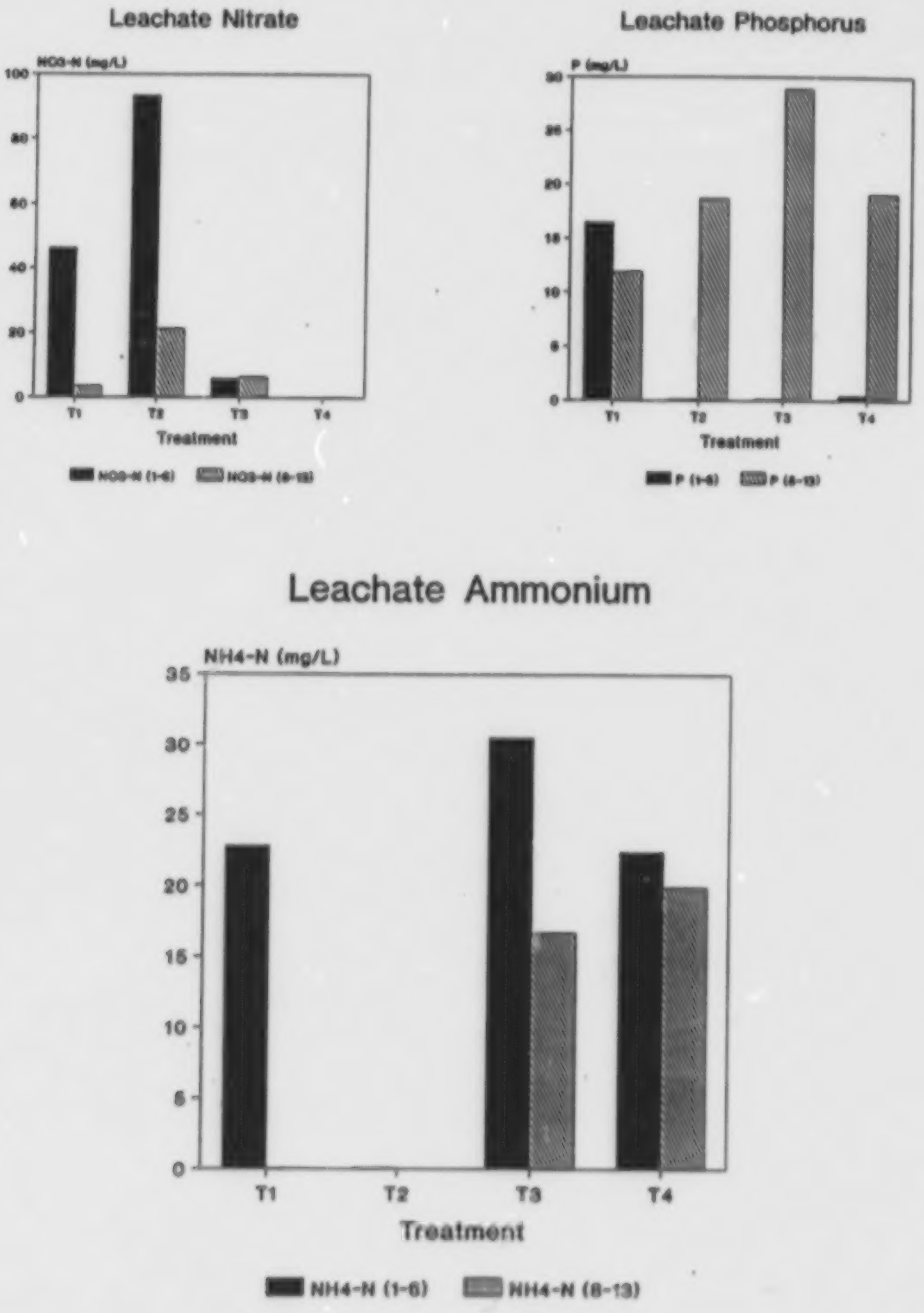


Figure 13. Leachate Oil and Grease

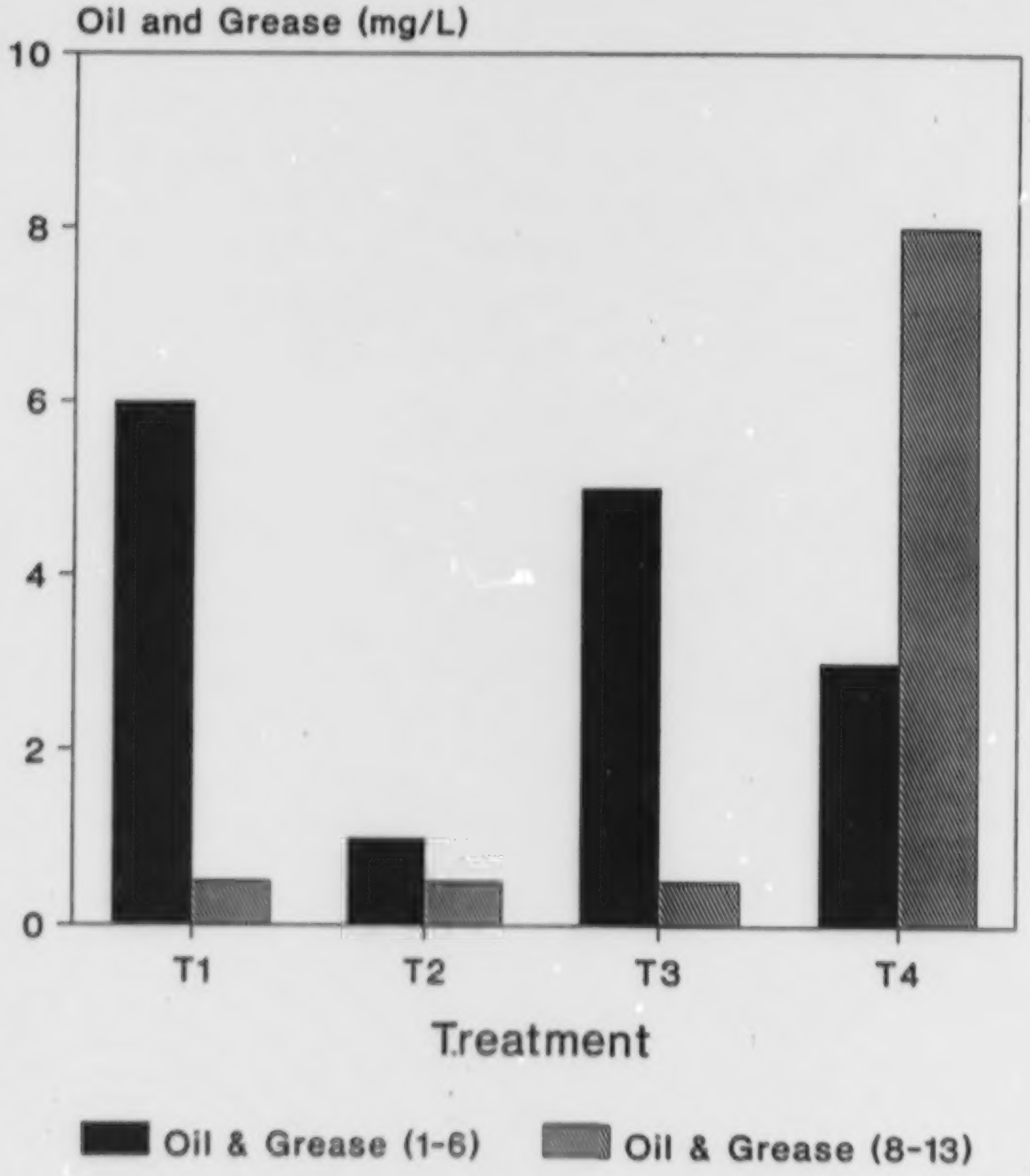


Figure 14. Leachate Metals

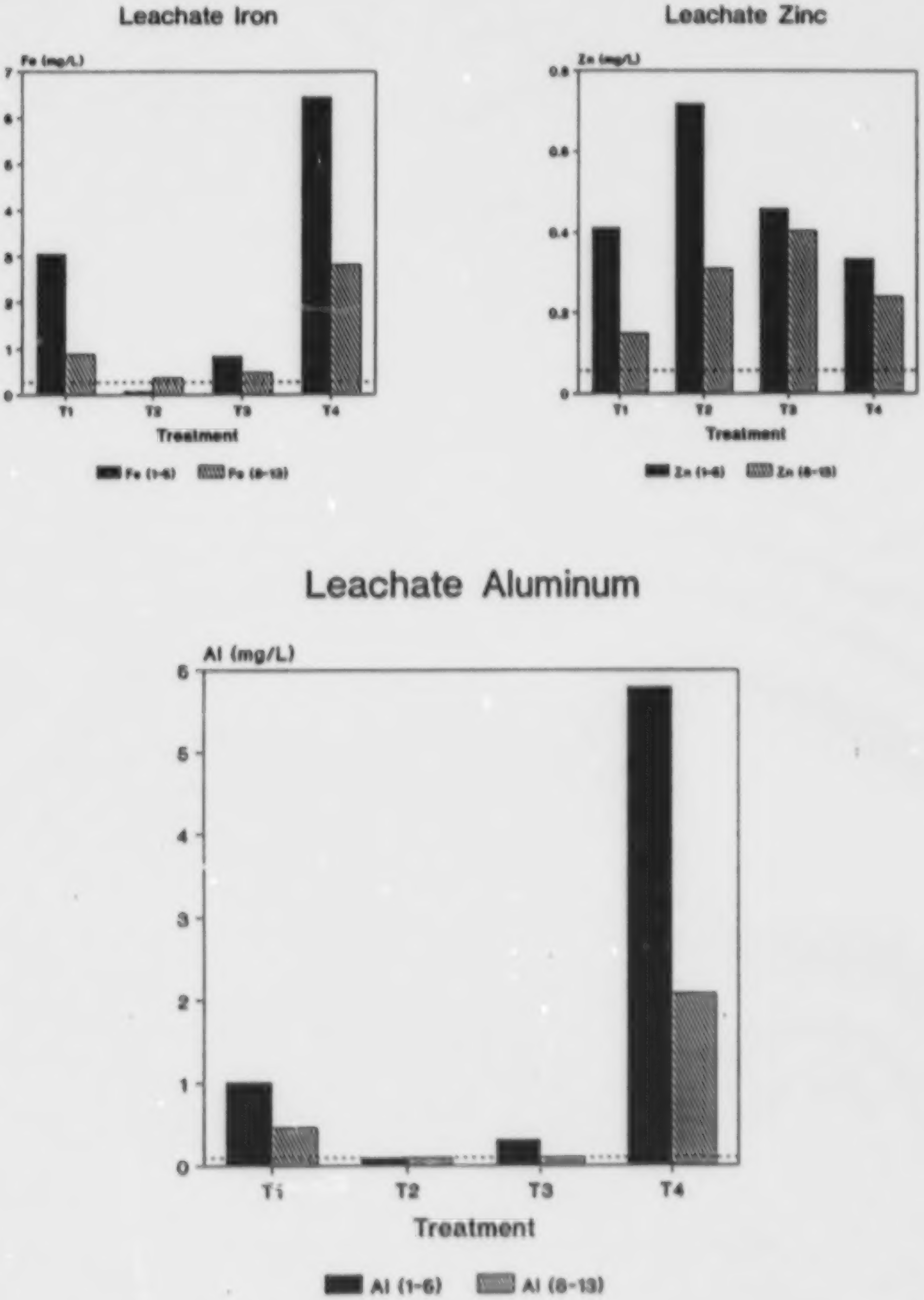
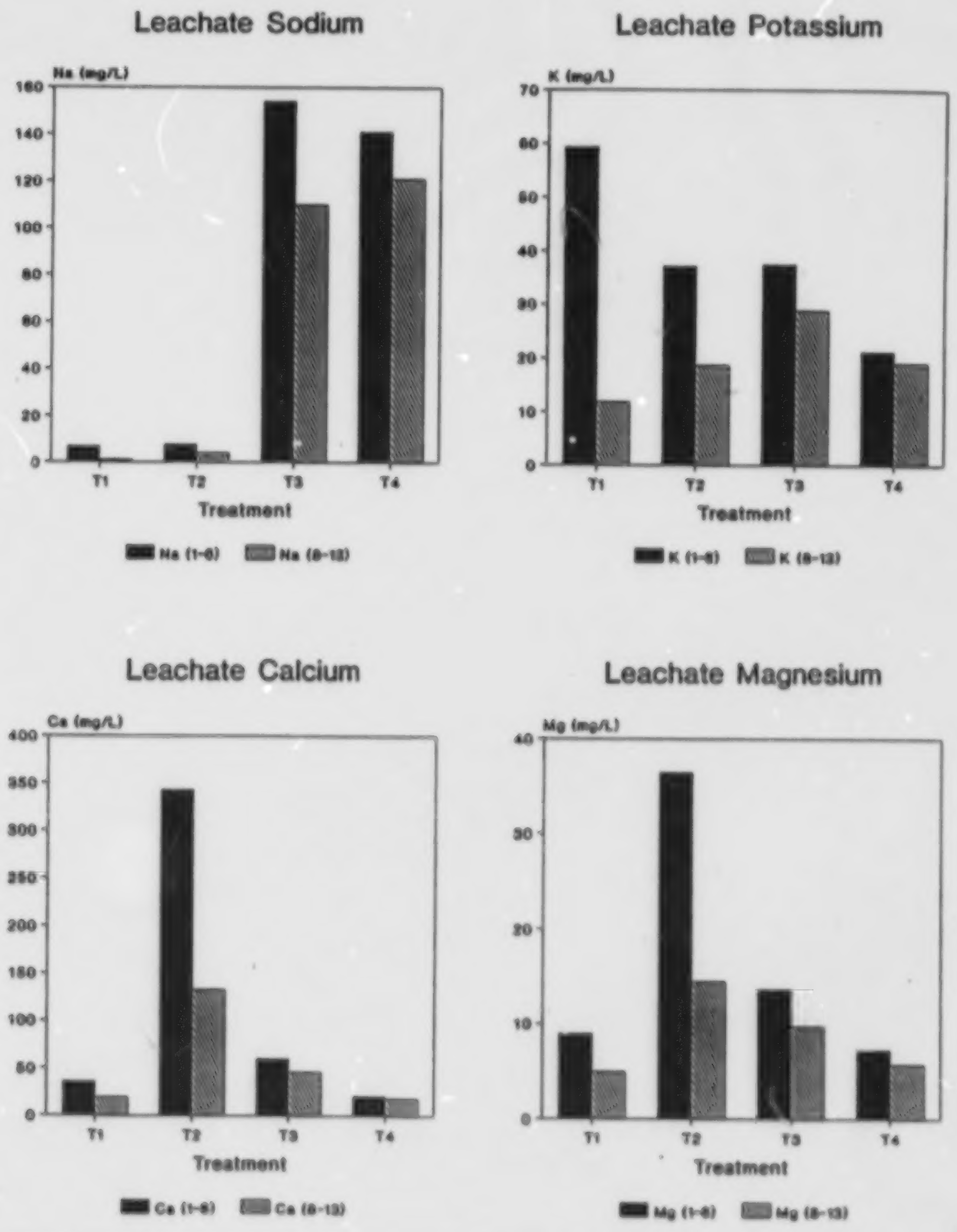


Figure 15. Leachate Basic Cations



Leachate Sodium

Leachate Potassium

Leachate Calcium

Leachate Magnesium

3.6 Leachate Bioassays

Two bioassays, Microtox™ and a modified 21 day *Daphnia magna* test, were performed to evaluate the toxicity of the leachates. Due to the lack of leachate collected, limited quantities were available for laboratory replicates during testing.

Microtox™

Results from Microtox™ testing showed that EC_{50}'s (at 5, 15, and either 20, 25 or 30 minutes exposure) were greater than 100% for all samples (Table 7). However, by plotting the Microtox™ luminescence values against concentration for the different treatments and leaching intervals, a more complex pattern is revealed. Figure 16 compares the data for the four treatments over three leachate collection periods: 1) the pre-rain period when the columns were allowed to drain, 2) days 1 to 6, and 3) days 8-13. In all cases, the T2 (sand and muskeg) leachate *stimulates* the *Photobacterium phospherium* and there is an increase in luminescence. During the pre-rain period, the other three treatments show a *decline* in luminescence with increasing concentration. For the leachate collected in days 1 to 6, an increase in luminescence was detected at low concentrations for all treatments, but there was a decline at 90% concentration, especially for T4. This trend is also visible for days 8-13 for T4, while the T1 and T3 luminescence values flatten out. Figure 17 compares the pattern for the three time intervals for the two fine tails amended treatments. Both T3 and T4 exhibit a progressive reduction in the toxicity of the leachates with time.

The data suggest that the soil mixtures have both a positive and negative influence on bacteria luminescence. It appears that dissolved organic carbon from the muskeg is a substrate for the bacteria, causing the positive effect. The data for T4 suggests that some component of the fine tails is a source of toxicity. However, this toxicity decreases over time suggesting an effect of dilution (with increasing rainfall) and/or biodegradation.

Daphnia magna

Results from testing with *D. magna* are shown in Table 8, raw data are documented in Appendix B. Three mortalities occurred during the test, two after day 16 and one after day 18. These mortalities do not diminish the significance of these results since, in each case, death occurred late in the test. Reproduction was significantly ($P \leq 0.05$) lower in leachates collected during days 1-6 from Treatments 2, 3, and 4 than in the

Table 7. Microtox™ Testing Results on Leachates from Three Collection Periods

Sample	EC_{50} (%)								
	Pre-rainfall leachate			Leachate from days 1-6			Leachate from days 8-13		
	5 min	15 min	20-30 min	5 min	15 min	20-30 min	5 min	15 min	20-30 min
T1	> 100%	> 100%	> 100%	> 100%	> 100%	> 100%	> 100%	> 100%	> 100%
T2	> 100%	> 100%	> 100%	> 100%	> 100%	> 100%	> 100%	> 100%	> 100%
T3	> 100%	> 100%	> 100%	> 100%	> 100%	> 100%	> 100%	> 100%	> 100%
T4	> 100%	> 100%	> 100%	> 100%	> 100%	> 100%	> 100%	> 100%	> 100%

Figure 16. 30 Minute Microtox™ Results for Three Leaching Periods

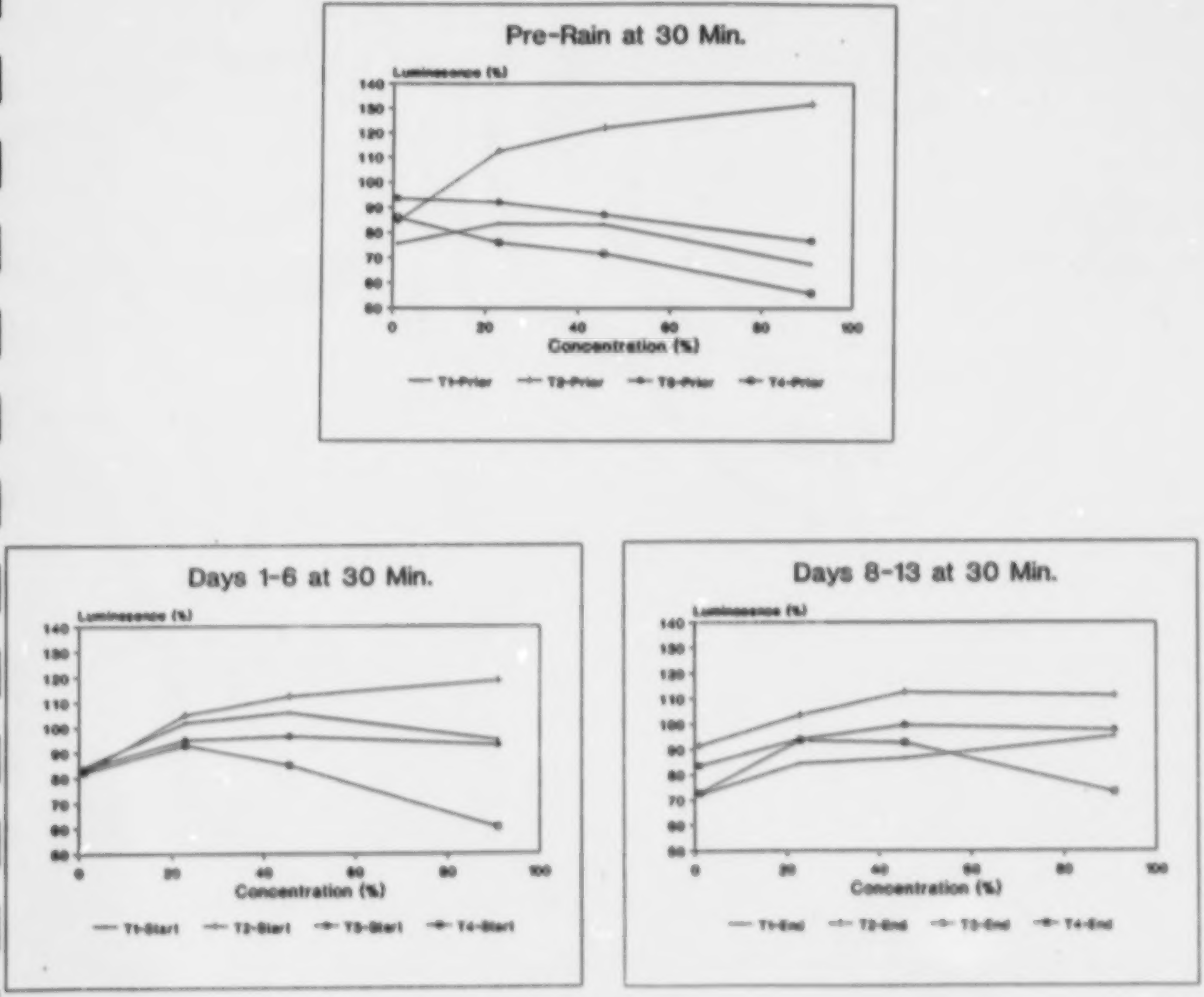
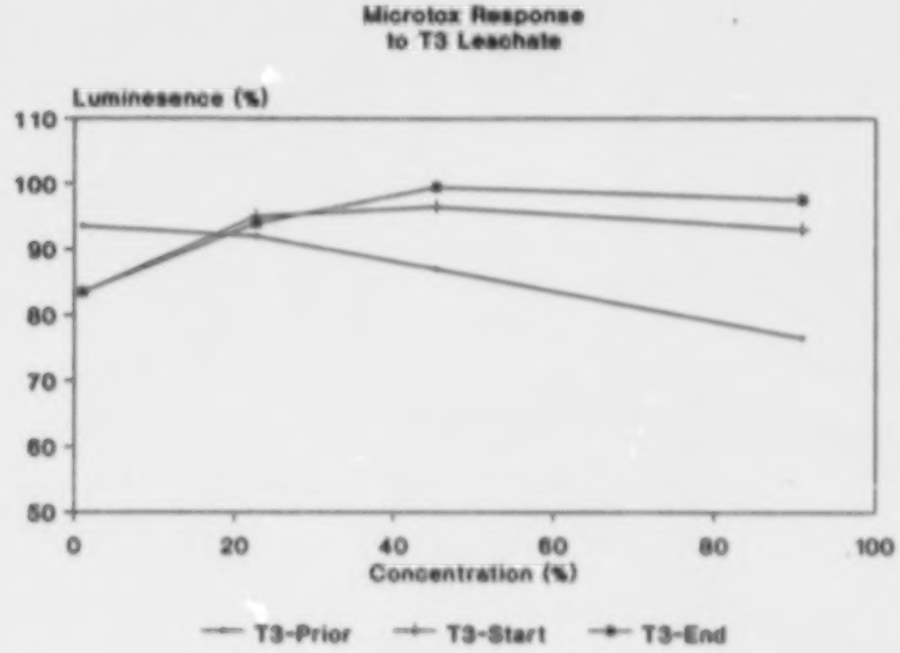


Figure 17. Microtox™ Response to T3 and T4



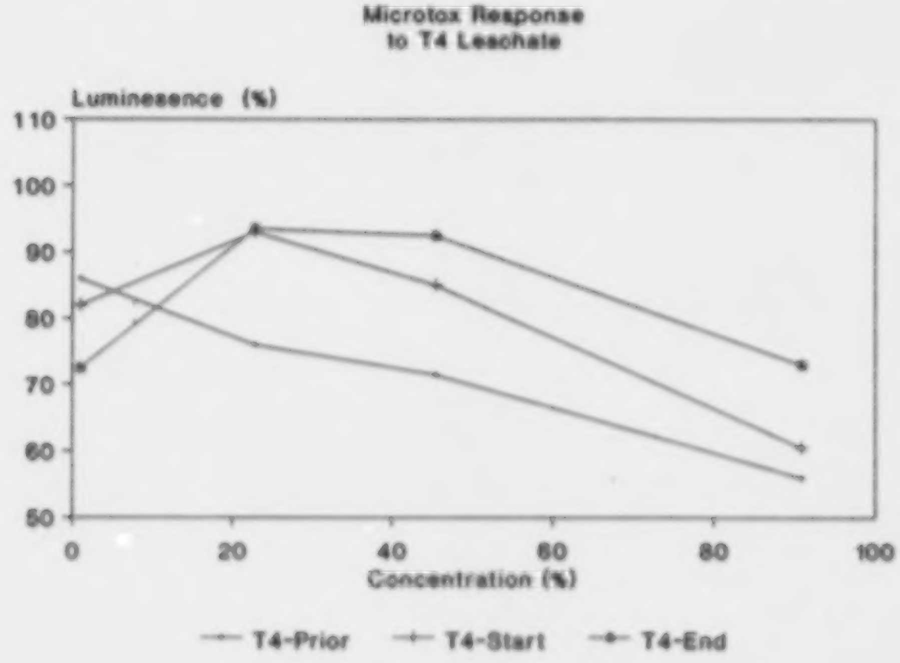


Table 8. **Modified 21 day *Daphnia magna* test.**

Sample	Replicate	Survival to 21 day	Young Produced	Mean # Young Produced[1]
Control	A	1	87	83.2 (4.9)
	B	1	83	
	C	1	77	
	D	1	89	
	E	1	80	
Days 1−6				
T1	A	1	55	74.3 (19.5)
	B	0	74	
	C	1	94	
T2	A	1	60	37.7 (19.4)
	B	1	28	
	C	1	25	
T3	A	0	62	46.0 (19.7)
	B	1	24	
	C	1	52	
T4	A	1	38	45.0 (15.7)
	B	1	63	
	C	1	34	
Days 8−13				
T1	A	1	151	127.0 (31.7)
	B	1	91	
	C	1	139	
T2	A	1	140	129.0 (9.6)
	B	1	122	
	C	0	125	
T3	A	1	100	103.0 (57.6)
	B	1	47	
	C	1	162	
T4	A	1	139	115.7 (31.4)
	B	1	80	
	C	1	128	

1. Number in brackets is standard deviation.

test control. The number of young produced were 37.7, 46.0, and 45.0 for T2, T3, and T4 from leachate collected on days 1-6 as compared to a test control reproduction of 83.2 . Reproduction in leachates from days 8-13 were all higher than in the test control; that is, had increased over values obtained in the earlier rain events, indicating a decrease in toxicity.

4.0 DISCUSSION

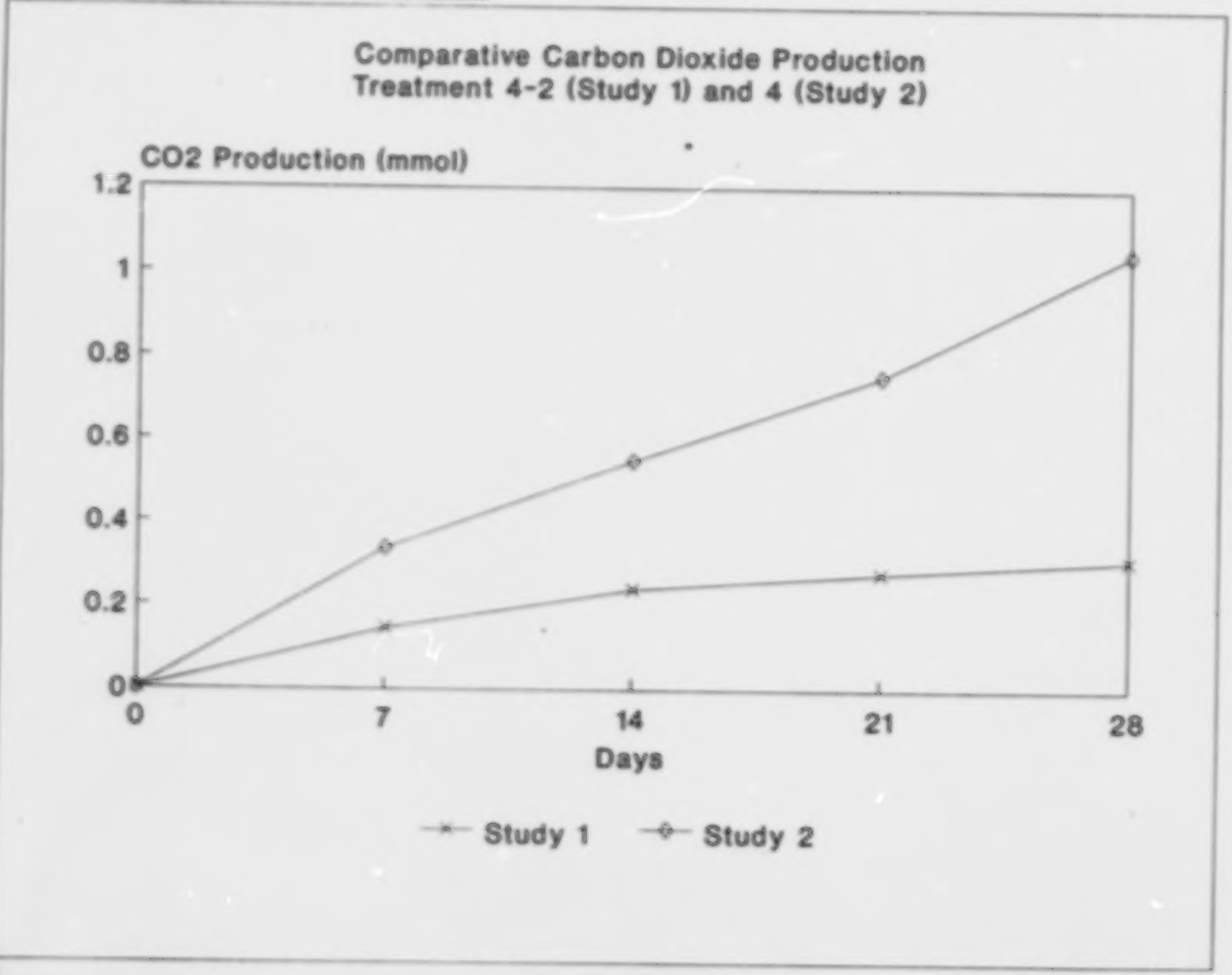
4.1 Reclamation Potential

Results from biometer flask experiments indicate that the addition of fine tails will stimulate processes of microbial degradation, despite low levels of nitrate. Figure 18 compares the CO_2 evolution curve from T4 in this study (Study 2) to the curve derived from the "high fine tails" field soils which were sampled in July 1991 (Study 1; Hamilton, 1992). When comparing the two curves, it is important to ignore the initial flush of CO_2 over the first seven days because this is a result of initial disturbances to the soils which provide oxygen to previously dormant aerobic microorganisms. The rate of CO_2 production (e.g. slope of the line) from the Study 1 soil is only slightly positive in contrast to the steeper slope for the Study 2 soil. Over the final 21 day period, more than eight times the CO_2 was evolved from the Study 2 soil than the Study 1 soil. This is indicative of the first "wave" of microorganisms which attack and break down easily biodegradable organic compounds. With time, only the resistant, stable organic compounds, including resynthesized compounds remain, and these are mineralized slowly. These stable compounds, analogous to humus in natural soils, are generally less likely to be toxic to organisms than more degradable compounds due to their low availability.

Nitrification is inhibited in the soils amended with fine tails and low nitrate levels appear to be the greatest limitation to progressive bioremediation, as well as to the production of vegetation biomass on the reclaimed sites. This situation is compounded by the evident high leachability of nitrate (Figure 12). As an anion, nitrate is very mobile in soils since it does not bind to the primarily negatively charged clay and organic matter particles. The annual fertilization of fine tails with nitrate would probably help maintain suitable rates of degradation which may be required to decrease levels of toxicants and to aid in the production of valuable soil humus. Nitrogen fertilizer compounds that contain nitrate (i.e., sodium nitrate), rather than ammonium or urea, would be preferred since the nitrification of these compounds (i.e., oxidation to bioavailable nitrate) appears to be inhibited by fine tails. Mid-summer applications may minimize leaching losses. Fertilization with NO_3^- should be supplemented with P and tillage (Bartha, 1986). Liming should not be required given the neutral pH and high buffering capacity of the soils.

In a study conducted to assess the biodegradation of a heavy atmospheric gas oil, Mott et al. (1990) found that biodegradation was inversely proportional to aggregate size before application, and that soil surface preparation into fine aggregates may be more beneficial than post-application tillage. Fine aggregates, as opposed to coarse aggregates, will increase the oil to soil contact. Due to their low clay and silt content, the reclaimed soils at the Suncor site are poorly aggregated and hence may benefit from supplementation with fine

Figure 18. Comparative Carbon Dioxide Production.



tails. This is one of the reasons why the Norwest study was initiated. Due to the difficult nature of the fine tails, post application tillage is unlikely to be feasible therefore, breaking the soils up before applying the fine tails may be beneficial if the soils have already received muskeg amendments and have been seeded. If nearby natural soils are proposed as possible land treatment sites, a detailed soil assessment will be required to determine application strategies.

4.2 Leachates and Water Quality

For most compounds in the leachate, there was a marked reduction in concentrations found in the second six-day period compared with the first. These compounds include oil and grease, conductivity, iron, zinc, aluminum, nitrate, ammonium and the exchangeable cations (K, Ca, Mg, Na). The only element which showed a consistent increase in the second cycle was phosphorus. The oil and grease content of T4 was higher in the second cycle, but this probably reflected the very slow hydraulic conductivity.

From the perspective of water quality, only three metals (Fe, Zn, and Al) exceeded the Canadian Water Quality concentration guidelines for aquatic habitat. All showed declining concentrations in the second cycle which point to an ultimate reduction below guidelines. Field monitoring would be required for these and any other compound to ascertain that concentrations continue to decrease. The on-going cycles of physical and chemical weathering in the soils could cause certain elements and compounds to have re-newed availability. If followed by a flush of gravitational water, such as during spring snowmelt, there could be a temporary increase in concentrations.

Beyond the question of concentrations, there is the issue of contaminant loadings. The actual volumes of leachate which can be expected to move through the soil profile is small, due to a combination of moderate rainfall, summer evapotransformation, and the very low saturated hydraulic conductivity of the fine tails amended soils (cf. Section 3.4). Thus contaminant loadings (volume x concentration) may also be relatively low. Any leachates moving to groundwater would be diluted by regional groundwater flow before moving to the Athabasca River or other surface water bodies. This anticipated situation could change if large areas are utilized for land treatment, or if multiple fine tails loadings are applied to a single site. This could be managed by applying the fine tails in block areas or cells, and spacing the timing of applications in adjoining cells. This is analogous to forest harvest practices whereby cut blocks are sequenced to avoid cutting adjacent blocks in subsequent years.

Surface runoff process are not addressed in this report. Given the low saturated hydraulic conductivities and the tendency for the hydrocarbons to push the water from the soil pores, there is a high potential for contaminated water to pond on the surface where it may runoff during rainfall. This could be a concern on both level areas and areas of shallow slopes. Thus stormwater retention systems including small dykes and sedimentation ponds would be required for most sites, while sites with considerable slopes should be avoided. Constructed wetlands are one option for the handling of surface runoff.

5.0 CONCLUSIONS AND RECOMMENDATIONS

Before land treatment can proceed, it is recommended that additional research be conducted in the following areas:

i) Monitoring of leachate quantity and quality should be monitored in field-scale trials for field soils. Sampling lysimeters can be installed in the old Norwest plots as well as in plots with freshly applied fine tails. They should be sampled on a regular basis, supplemented by more intense sampling during snowmelt and during period of heavy rainfall.

ii) An assessment of the roles of muskeg addition, fertilization and tillage on biodegradation rates should be undertaken. This could start with bench scale tests followed by field plot studies.

iii) A comparative examination of biodegradation on dyke soils and natural soils on the Suncor lease should be initiated.

iv) A study is required to assess surface runoff processes and the potential for the delivery of contaminants to surface water.

v) The development of a plant bioassay is required to supplement animal bioassays.

vi) Since nitrification was inhibited by find tails, there is a need to assess the potential for nitrogen-fixing plant species to promote biodegradation.

vii) Ultimately, Suncor should consider a field pilot study at a spatial scale larger than the 10 m2 plots currently in place.

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APPENDIX 1

RAW DATA - CHEMICAL AND PHYSICAL

ASL

CHEMICAL ANALYSIS REPORT

Date: Mar. 27, 1992

ASL File No. 2187C

Report On: Soil Analysis (3/144-19.1)

Report To: E.V.S. Consultants Ltd.
195 Pemberton Avenue
North Vancouver, BC
V7P 2R4

Attention: Mr. Hugh Hamilton

Date Received: Mar. 17, 1992

METHODOLOGY

Moisture

This analysis is carried out gravimetrically by drying the sample to constant weight at 103 C.

Metals

These analyses are carried out using procedures that are consistent with the requirements of the appropriate regulatory agencies and adapted from U.S. EPA Method 3050 (Publ. # SW-846, 3rd ed., Washington, DC 20460). The procedures involve a digestion using a combination of nitric and hydrochloric acids. The resulting extract is bulked to volume with deionized/distilled water. The digested portion is then analysed by a variety of instrumental techniques, which may include specific atomic absorption spectrophotometric techniques (AAS) and/or atomic emission spectrophotometry (ICP), to obtain the required detection limit for each element. Specific details are available upon request.

PLEASE NOTE (When the following elements are reported):

Aluminum, barium, calcium, chromium, iron, magnesium, manganese, molybdenum and vanadium are often associated with the silicate matrix of the sediment. Because of this, the recoveries of these elements may be low using the specified digestion. From an environmental standpoint, this is not usually of concern since the "available" metals are typically the fraction of interest.

Conventional Parameters

These analyses are carried out in accordance with procedures described in "Standard Methods for the Examination of Water and Wastewater" 17th Ed. published by the American Public Health Association, 1989. Further details are available on request.

Oil and Grease

This analysis is carried out by extracting the sample with hexane. The extract thus produced is evaporated to dryness and the residue weighed to determine gravimetric oil and grease.

Total Extractable Hydrocarbons

This analysis is carried out in accordance with U.S. EPA Method 3550/8015. This procedure involves hexane extraction followed by analysis of the extract by capillary column gas chromatography with flame ionization detection.

COMMENTS

The sample were initial submitted on March 17,1992 in plastic bags, then later submitted on March 20,1992 in glass jars (except for T2-A,B,C insufficient sample).

The bag samples were used to analyzes all moisture and total metals along with oil & grease (O&G) and total extractable hydrocarbons (TEH) for samples T1-A,B,C and T2-A,B,C. The analyses for O&G and TEH for samples T3-A,B,C and T4-A,B.C were performed using the glass jars.

The chromatographic traces for the TEH are located in back of report.

ASL ANALYTICAL SERVICE LABORATORIES LTD.
per:

Scott Hannam
Supervisor, Trace Organics Lab

RESULTS OF ANALYSIS - Sediment/Soil

Parameter		T1-A	T1-A Dup.	T1-B	T1-C	T2-A
Physical Tests						
Moisture	%	18.2	-	19.0	18.9	30.3
Total Metals						
Arsenic	T-As	0.79	0.66	0.64	0.72	0.68
Barium	T-Ba	5.4	5.4	5.2	5.8	18.4
Cadmium	T-Cd	<2.0	<2.0	<2.0	<2.0	<2.0
Chromium	T-Cr	<2.0	<2.0	<2.0	<2.0	<2.0
Cobalt	T-Co	<2.0	<2.0	<2.0	<2.0	<2.0
Copper	T-Cu	1.1	1.2	<1.0	<1.0	2.0
Lead	T-Pb	<10	<10	<10	<10	<10
Mercury	T-Hg	0.005	<0.005	<0.005	<0.005	0.010
Molybdenum	T-Mo	<4.0	<4.0	<4.0	<4.0	<4.0
Nickel	T-Ni	<2.0	<2.0	<2.0	<2.0	3.1
Selenium	T-Se	<0.10	<0.10	<0.10	<0.10	<0.10
Silver	T-Ag	<2.0	<2.0	<2.0	<2.0	<2.0
Tin	T-Sn	<30	<30	<30	<30	<30
Zinc	T-Zn	4.8	4.9	4.1	5.0	33.5
Extractables						
Oil and Grease		570	-	580	800	990
Total Extractable Hydrocarbons		106	-	88	302	409

< = Less than the detection limit indicated.
Results are expressed as milligrams per dry kilogram of sample
except moisture which is expressed as percent.
Dup. = Duplicate.

RESULTS OF ANALYSIS - Sediment/Soil

Parameter		T2-A Dup.	T2-B	T2-C	T3-A	T3-B
Physical Tests						
Moisture	%	-	29.0	23.8	26.8	26.5
Total Metals						
Arsenic	T-As	-	0.70	0.75	1.24	1.26
Barium	T-Ba	-	17.6	17.5	23.7	24.0
Cadmium	T-Cd	-	<2.0	<2.0	<2.0	<2.0
Chromium	T-Cr	-	2.5	<2.0	8.3	8.5
Cobalt	T-Co	-	<2.0	<2.0	3.6	3.4
Copper	T-Cu	-	2.6	2.0	3.7	3.4
Lead	T-Pb	-	<10	<10	<10	<10
Mercury	T-Hg	-	0.009	0.009	0.012	0.022
Molybdenum	T-Mo	-	<4.0	<4.0	<4.0	<4.0
Nickel	T-Ni	-	2.7	2.2	11.8	11.3
Selenium	T-Se	-	<0.10	<0.10	<0.10	<0.10
Silver	T-Ag	-	<2.0	<2.0	<2.0	<2.0
Tin	T-Sn	-	<30	<30	<30	<30
Zinc	T-Zn	-	18.6	23.5	18.8	16.3
Extractables						
Oil and Grease		1110	980	820	22400	21700
Total Extractable Hydrocarbons		398	442	368	4690	9680

< = Less than the detection limit indicated.
Results are expressed as milligrams per dry kilogram of sample
except moisture which is expressed as percent.
Dup. = Duplicate.

RESULTS OF ANALYSIS - Sediment/Soil

Parameter		T3-B Dup.	T3-C	T4-A	T4-B	T4-C
Physical Tests						
Moisture	%	-	28.5	38.2	38.9	43.6
Total Metals						
Arsenic	T-As	1.01	1.36	1.53	1.84	2.20
Barium	T-Ba	24.4	24.5	33.5	33.8	39.4
Cadmium	T-Cd	<2.0	<2.0	<2.0	<2.0	<2.0
Chromium	T-Cr	8.3	8.3	12.9	12.9	15.2
Cobalt	T-Co	3.5	3.4	4.5	4.7	6.3
Copper	T-Cu	3.5	3.3	4.0	4.2	6.1
Lead	T-Pb	<10	<10	<10	<10	<10
Mercury	T-Hg	0.014	0.014	0.014	0.013	0.018
Molybdenum	T-Mo	<4.0	<4.0	<4.0	<4.0	<4.0
Nickel	T-Ni	11.8	11.1	17.8	18.0	26.2
Selenium	T-Se	<0.10	<0.10	0.13	0.13	0.18
Silver	T-Ag	<2.0	<2.0	<2.0	<2.0	<2.0
Tin	T-Sn	<30	<30	<30	<30	<30
Zinc	T-Zn	18.7	16.7	19.5	19.5	25.3
Extractables						
Oil and Grease		-	22500	29500	25800	34200
Total Extractable Hydrocarbons		-	13900	14600	15900	6600

< = Less than the detection limit indicated.
Results are expressed as milligrams per dry kilogram of sample
except moisture which is expressed as percent.
Dup. = Duplicate.

End of Report

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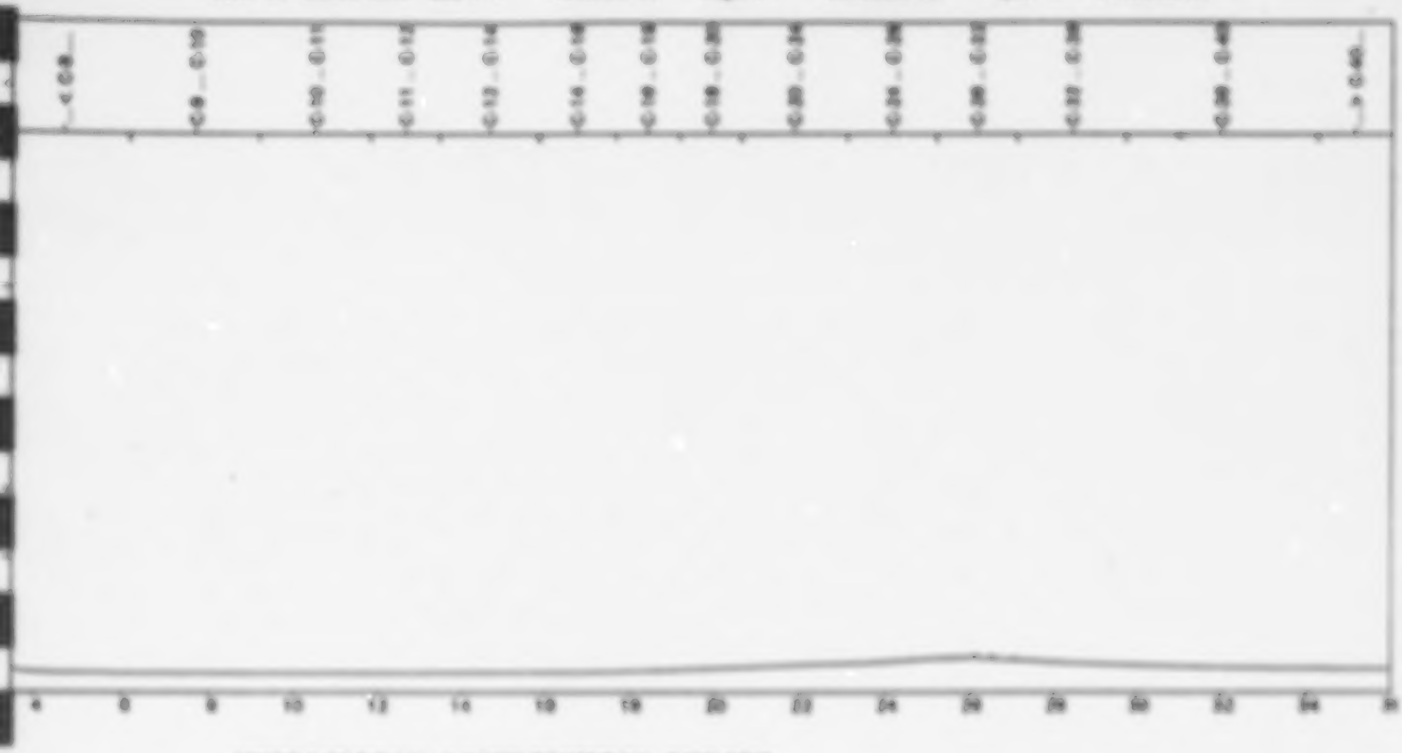

HYDROCARBON DISTRIBUTION REPORT

SAMPLE: 2187-3 (T1-6)

Petroleum Constituents Table

Name	Carbon Number
Gasolines	C-5 to C-14
Aviation Fuels	C-6 to C-18
Diesel Fuels	C-8 to C-20
Kerosenes	C-9 to C-18
Bunker Oil	C-9 and higher
Lubricating Oils	C-17 and higher
Waxes	C-20 and higher

The above table can be used to obtain a qualitative determination of the type of petroleum product present in any given sample. However the use of carbon number ranges is limited since many of the products listed in the table have overlapping carbon number ranges. A secondary confirmation of the type of material present in the sample can be obtained from comparision of the sample chromatogram to those obtained from pure commercial petroleum formulations.

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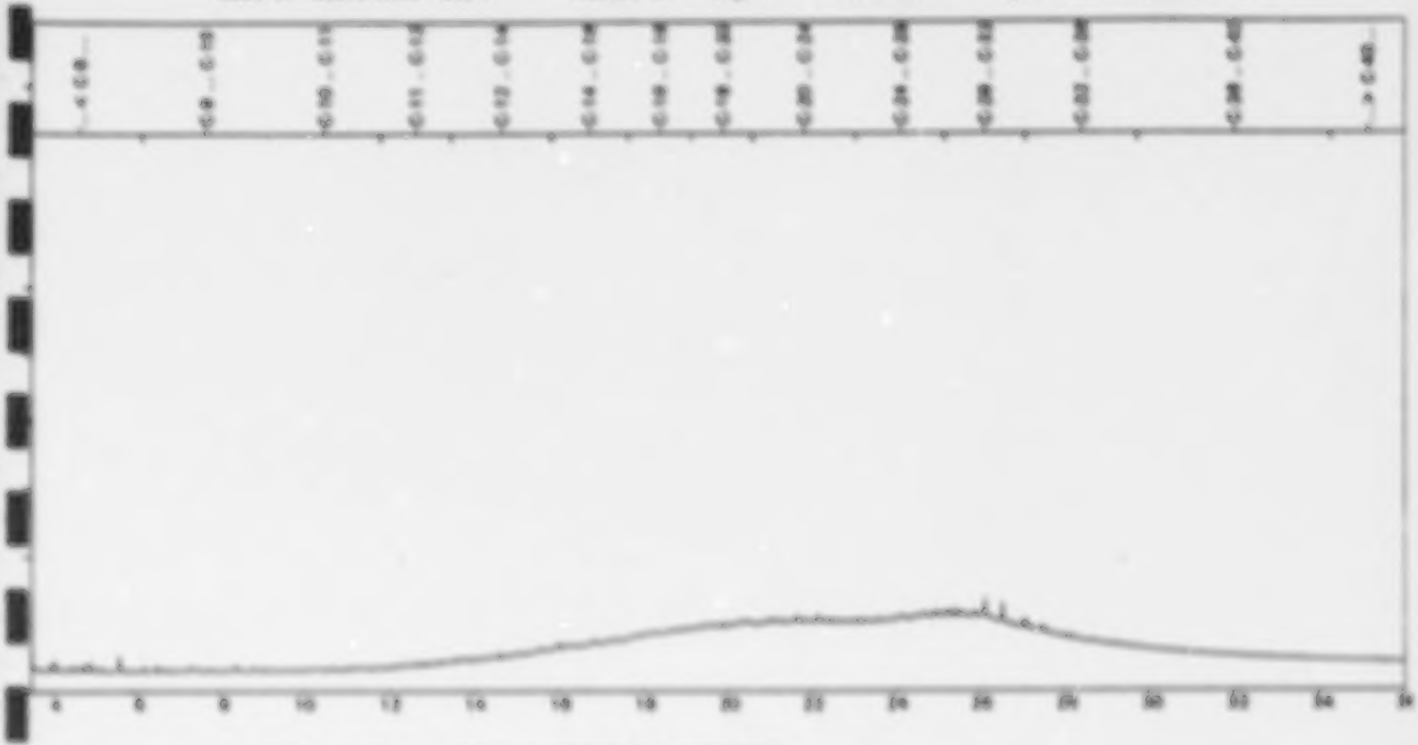

HYDROCARBON DISTRIBUTION REPORT

SAMPLE: 2187-7R XS (T3-A)

Petroleum Constituents Table

Name	Carbon Number
Gasolines	C-5 to C-14
Aviation Fuels	C-6 to C-18
Diesel Fuels	C-8 to C-20
Kerosenes	C-9 to C-18
Bunker Oil	C-9 and higher
Lubricating Oils	C-17 and higher
Waxes	C-20 and higher

The above table can be used to obtain a qualitative determination of the type of petroleum product present in any given sample. However the use of carbon number ranges is limited since many of the products listed in the table have overlapping carbon number ranges. A secondary confirmation of the type of material present in the sample can be obtained from comparision of the sample chromatogram to those obtained from pure commercial petroleum formulations.

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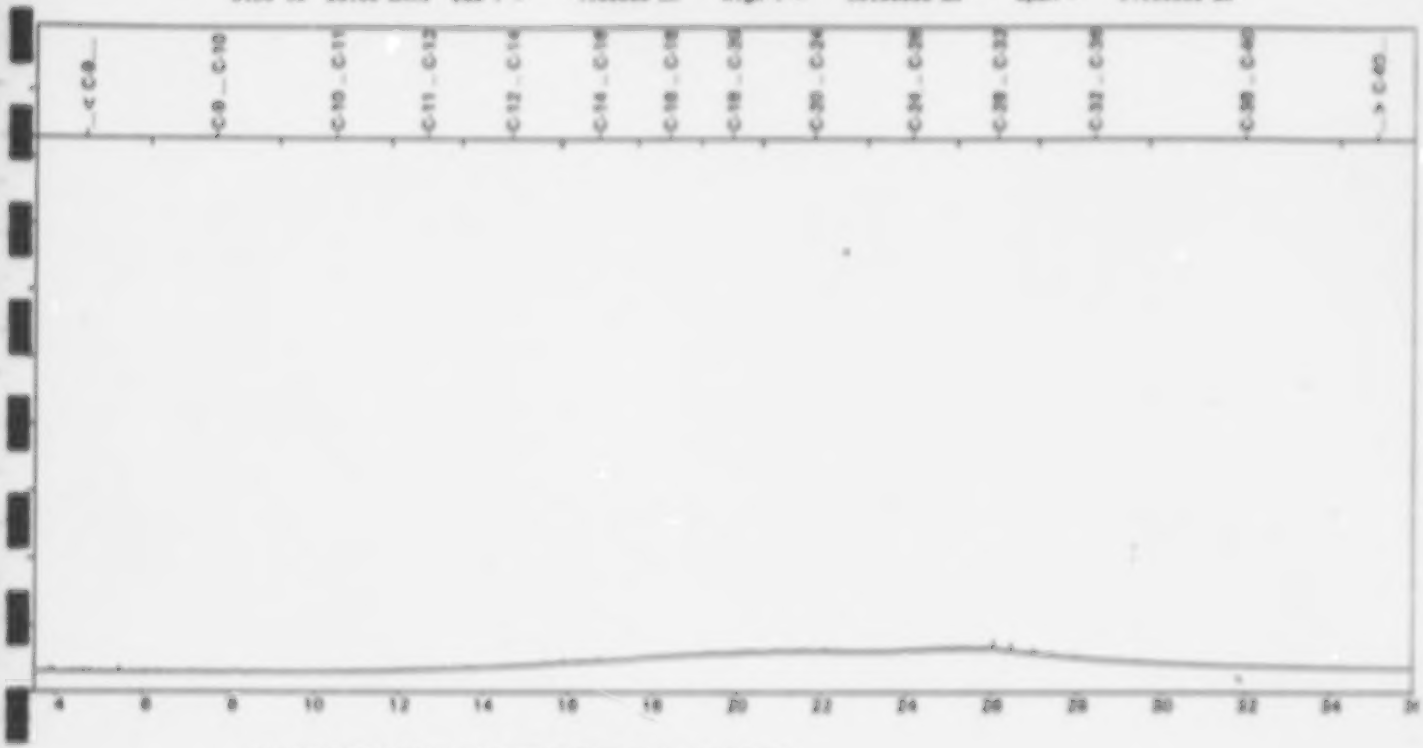


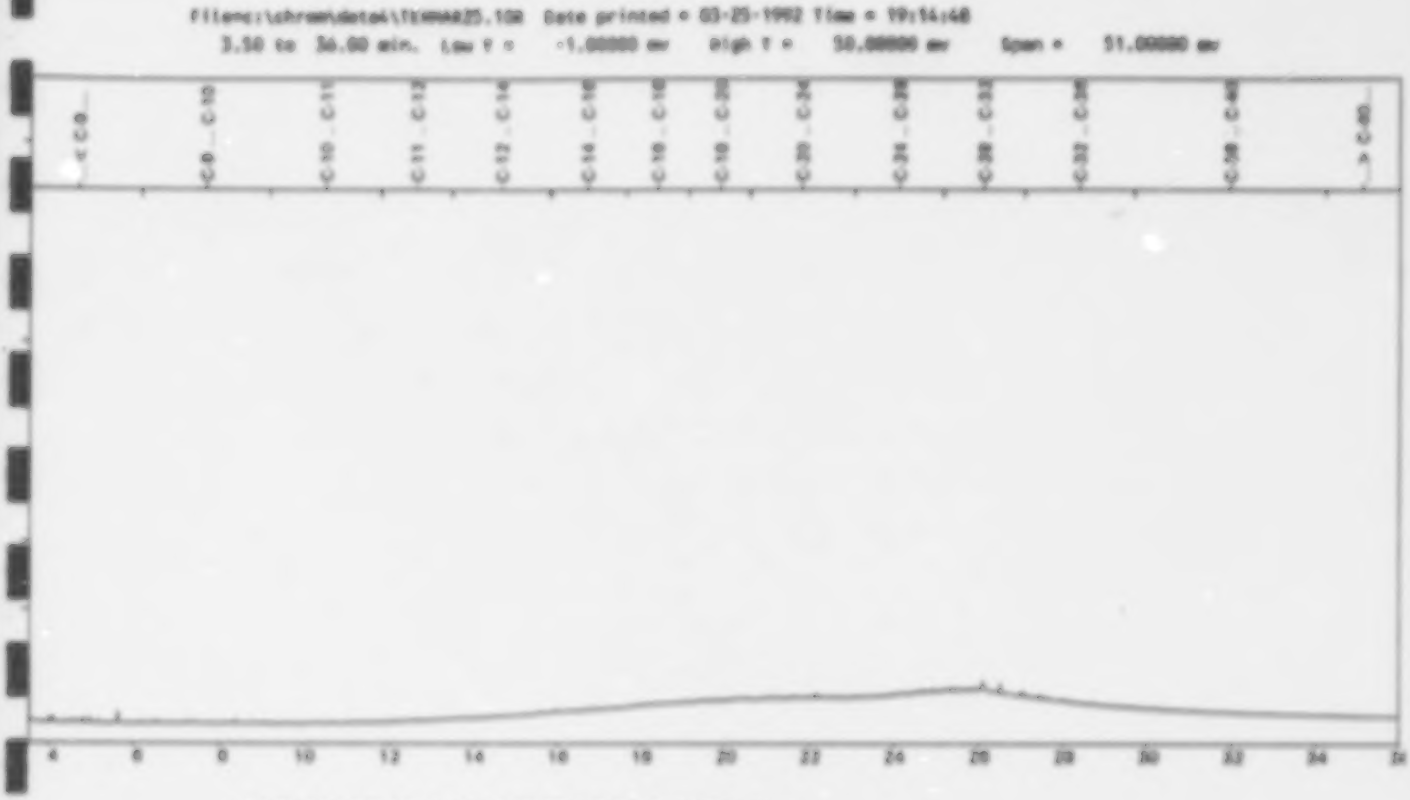
HYDROCARBON DISTRIBUTION REPORT

SAMPLE: 2187-8R X4 (T3-8)

Petroleum Constituents Table

Name	Carbon Number
Gasolines	C-5 to C-14
Aviation Fuels	C-6 to C-18
Diesel Fuels	C-8 to C-20
Kerosenes	C-9 to C-18
Bunker Oil	C-9 and higher
Lubricating Oils	C-17 and higher
Waxes	C-20 and higher

The above table can be used to obtain a qualitative determination of the type of petroleum product present in any given sample. However the use of carbon number ranges is limited since many of the products listed in the table have overlapping carbon number ranges. A secondary confirmation of the type of material present in the sample can be obtained from comparision of the sample chromatogram to those obtained from pure commercial petroleum formulations.



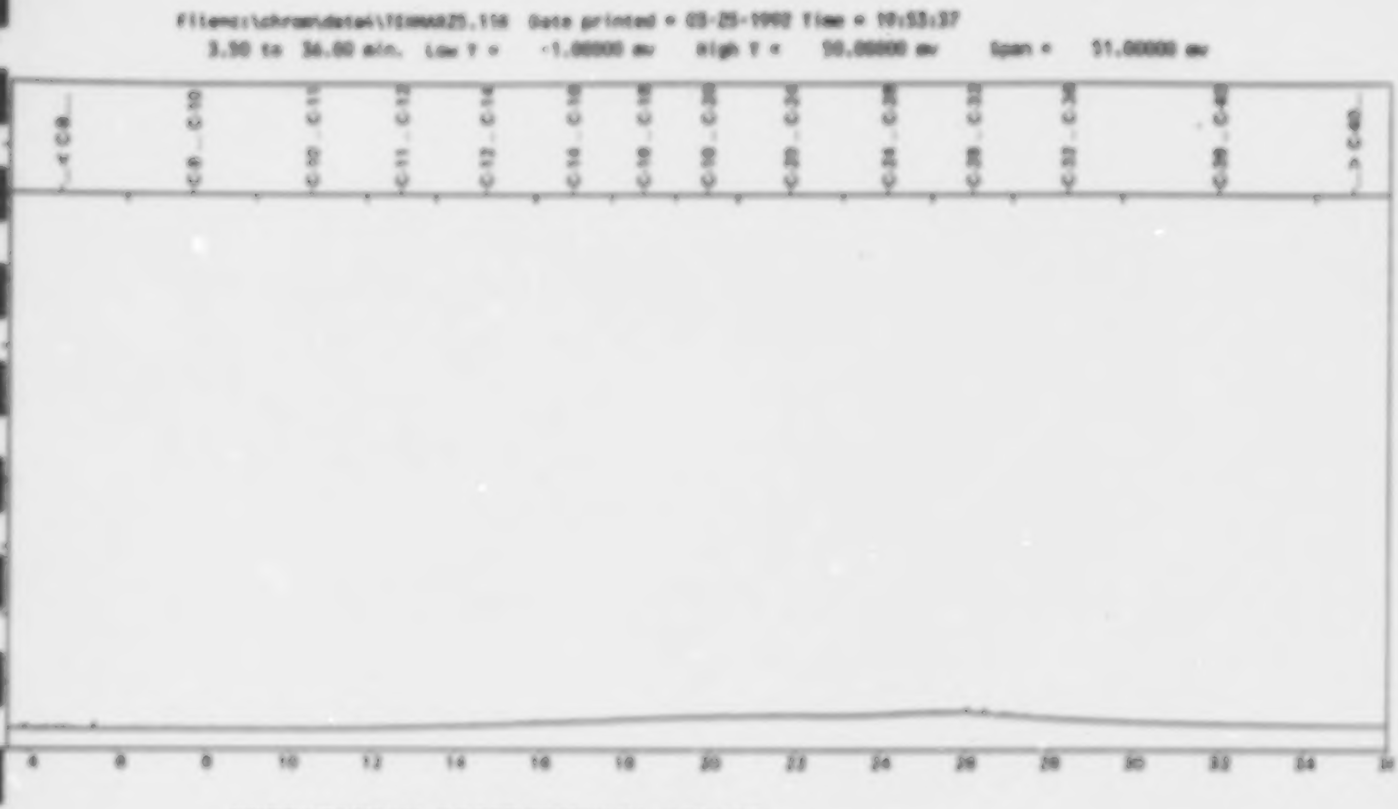
HYDROCARBON DISTRIBUTION REPORT

SAMPLE: 2187-9R X4 (T3-C)

Petroleum Constituents Table

Name	Carbon Number
Gasolines	C-5 to C-14
Aviation Fuels	C-6 to C-18
Diesel Fuels	C-8 to C-20
Kerosenes	C-9 to C-18
Bunker Oil	C-9 and higher
Lubricating Oils	C-17 and higher
Waxes	C-20 and higher

The above table can be used to obtain a qualitative determination of the type of petroleum product present in any given sample. However the use of carbon number ranges is limited since many of the products listed in the table have overlapping carbon number ranges. A secondary confirmation of the type of material present in the sample can be obtained from comparision of the sample chromatogram to those obtained from pure commercial petroleum formulations.



HYDROCARBON DISTRIBUTION REPORT

SAMPLE: 2187-10R X5 (T4-A)

Petroleum Constituents Table

Name	Carbon Number
Gasolines	C-5 to C-14
Aviation Fuels	C-6 to C-18
Diesel Fuels	C-8 to C-20
Kerosenes	C-9 to C-18
Bunker Oil	C-9 and higher
Lubricating Oils	C-17 and higher
Waxes	C-20 and higher

The above table can be used to obtain a qualitative determination of the type of petroleum product present in any given sample. However the use of carbon number ranges is limited since many of the products listed in the table have overlapping carbon number ranges. A secondary confirmation of the type of material present in the sample can be obtained from comparision of the sample chromatogram to those obtained from pure commercial petroleum formulations.

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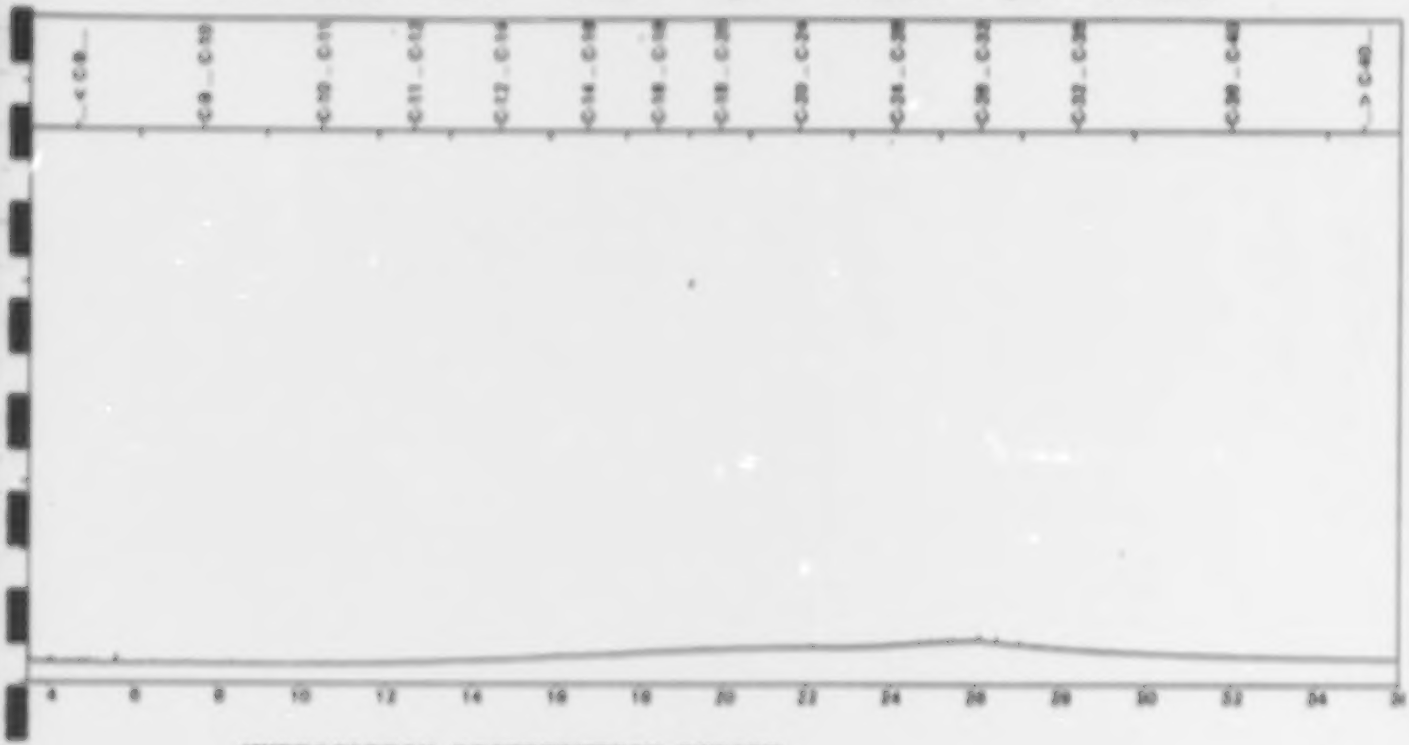

HYDROCARBON DISTRIBUTION REPORT

SAMPLE: 2187-11R X5 (T4-B)

Petroleum Constituents Table

Name	Carbon Number
Gasolines	C-5 to C-14
Aviation Fuels	C-6 to C-18
Diesel Fuels	C-8 to C-20
Kerosenes	C-9 to C-18
Bunker Oil	C-9 and higher
Lubricating Oils	C-17 and higher
Waxes	C-20 and higher

The above table can be used to obtain a qualitative determination of the type of petroleum product present in any given sample. However the use of carbon number ranges is limited since many of the products listed in the table have overlapping carbon number ranges. A secondary confirmation of the type of material present in the sample can be obtained from comparision of the sample chromatogram to those obtained from pure commercial petroleum formulations.

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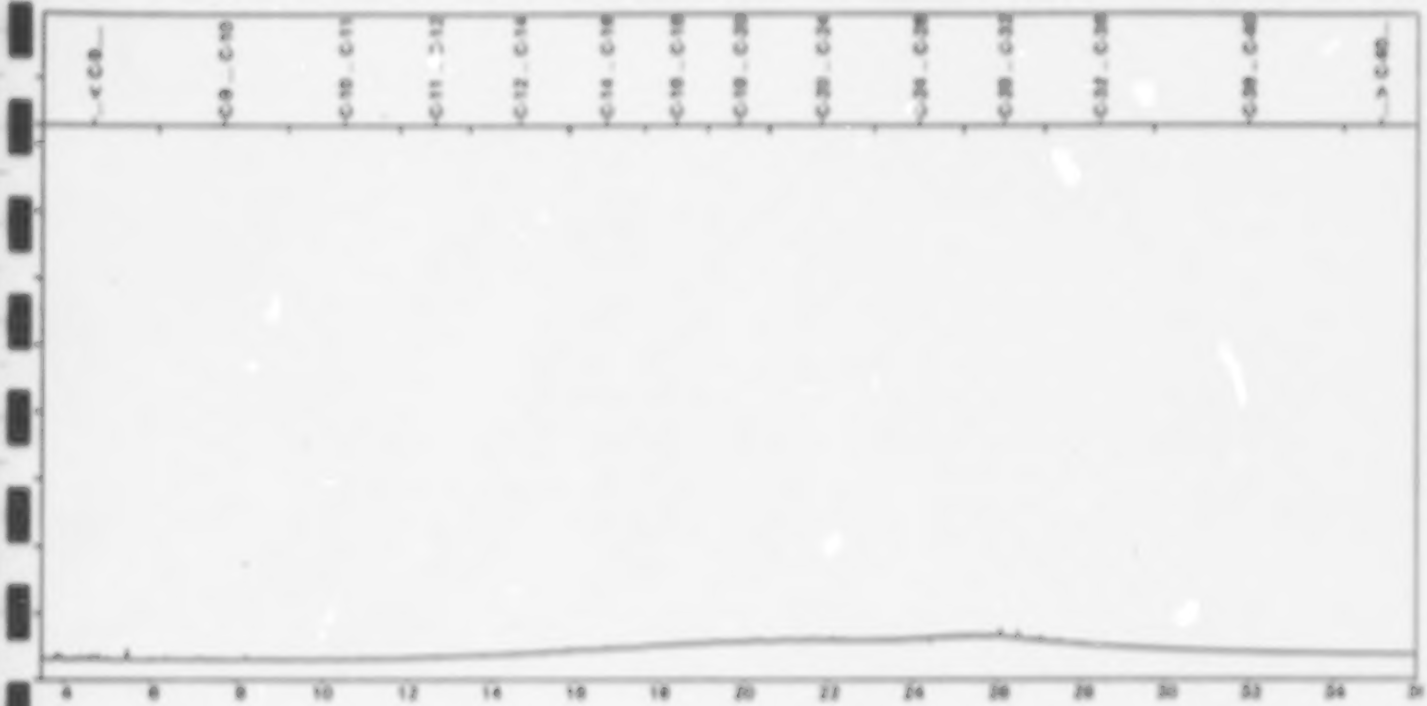

HYDROCARBON DISTRIBUTION REPORT

SAMPLE: 2187-12R X5 (T4-C)

Petroleum Constituents Table

Name	Carbon Number
Gasolines	C-5 to C-14
Aviation Fuels	C-6 to C-18
Diesel Fuels	C-8 to C-20
Kerosenes	C-9 to C-18
Bunker Oil	C-9 and higher
Lubricating Oils	C-17 and higher
Waxes	C-20 and higher

The above table can be used to obtain a qualitative determination of the type of petroleum product present in any given sample. However the use of carbon number ranges is limited since many of the products listed in the table have overlapping carbon number ranges. A secondary confirmation of the type of material present in the sample can be obtained from comparision of the sample chromatogram to those obtained from pure commercial petroleum formulations.

PSAI

Mar 31/92

EVS Hugh Hamilton

SAMPLE	pH	Buffered pH	CATION EXCHANGE CAPACITY (me/100gm) CEC	AVAILABLE (ppm) NH4-N	AVAILABLE (ppm) NO3-N	Salts (mmhos/cm) E.C.	Organic Matter (%) O.M.	Total Nitrogen (%) N	AVAILABLE Phosphorus (ppm) P	EXCHANGEABLE Potassium (me/100g) K	EXCHANGEABLE Calcium (me/100g) Ca	EXCHANGEABLE Magnesium (me/100g) Mg	EXCHANGEABLE SODIUM (me/100g) Na.	Zinc Zn	Iron Fe	Manganese Mn	Boron B	AVAILABLE Sulfate-Sulfur (ppm) S
T 1A	6.7	0.25	1.07	13.5	34	0.54		0.01	30	0.70	2.40	0.45	0.08					6.3
1B	6.9	.31	2.14	13.5	45	0.46		.01	28	.30	1.60	0.35	.24					51
1C	7.1	.22	2.50	10.5	30	0.46		.01	23	.25	2.10	0.40	.04					3.8
T 2A	7.3	9.0	16.4	13.5	20	1.62		.20	42	.10	26.5	1.60	.04					117
2B	7.4	8.4	20.7	10.5	20	1.80		.33	37	.14	28.0	1.85	.07					133
2C	7.4	6.2	18.2	10.5	51	2.40		.21	42	.14	26.5	1.75	.05					210
T 3A	7.8	4.6	10.5	16.5	26	1.78		.14	33	.35	16.0	1.45	.75					88
3B	7.8	4.7	10.2	13.5	16	1.64		.14	19	.25	15.0	1.40	.75					80
3C	7.8	4.7	9.3	21.0	16	1.60		.13	19	.30	15.0	1.30	.70					74
T 4A	7.6	19.2	23.6	59	34	1.30		.25	25	.45	11.0	2.35	2.20					51
4B	7.7	16.5	23.2	51	30	1.32		.23	19	.50	11.0	2.40	2.15					51
4C	7.7	13.9	22.5	38	20	0.86		.24	12	.50	9.0	2.00	1.95					48

COMMENTS:

ASL

CHEMICAL ANALYSIS REPORT

Date: Apr. 16, 1992

ASL File No. 2528C

Report On: Water Analysis (3/144-19.1)

Report To: E.V.S. Consultants Ltd.
195 Pemberton Avenue
North Vancouver, BC
V7P 2R4

Attention: Mr. Hugh Hamilton

Date Received: Apr. 06, 1992

METHODOLOGY

Conventional Parameters

These analyses are carried out in accordance with procedures described in "Standard Methods for the Examination of Water and Wastewater" 17th Ed. published by the American Public Health Association, 1989. Further details are available on request.

Metals

These analyses are carried out in accordance with procedures described in "Standard Methods for the Examination of Water and Wastewater" 17th Edition published by the American Public Health Association, 1989. The procedures involve a variety of instrumental analyses including atomic emission spectrophotometry (ICP) and atomic absorption spectrophotometry (AA) to obtain the required detection limit for each element. Specific details are available on request.

ASL ANALYTICAL SERVICE LABORATORIES LTD.
per:

Scott Hannam
Supervisor, Trace Organics Lab

RESULTS OF ANALYSIS - Water

Parameter		T1-X	T2-X	T3-X	T4-X	T1-Y
Physical Tests						
Conductivity umhos/cm		656	1830	1280	905	172
pH		7.18	7.77	8.14	8.27	7.68
Nutrients						
Ammonia Nitrogen	N	22.8	0.063	30.5	22.4	0.047
Nitrate Nitrogen	N	46.3	93.5	6.08	0.367	3.58
Total Phosphorus	P	15.8	0.211	0.269	2.72	3.09

< = Less than the detection limit indicated.
Results are expressed as milligrams per dry kilogram except for moisture (%).

ASL

RESULTS OF ANALYSIS - Water

File No. 2528C
Page 3

Parameter		T1-S	T2-S	T3-S	T4-S	T1-T
Total Metals						
Aluminum	T-Al	1.01	<0.20	0.31	5.79	0.46
Antimony	T-Sb	<0.20	<0.20	<0.20	<0.20	<0.20
Arsenic	T-As	<0.20	<0.20	<0.20	<0.20	<0.20
Barium	T-Ba	0.055	0.081	0.078	0.090	0.038
Beryllium	T-Be	<0.005	<0.005	<0.005	<0.005	<0.005
Bismuth	T-Bi	<0.10	<0.10	<0.10	<0.10	<0.10
Cadmium	T-Cd	<0.010	<0.010	<0.010	<0.010	<0.010
Calcium	T-Ca	36.1	343	60.7	20.8	19.2
Chromium	T-Cr	<0.015	<0.015	<0.015	<0.015	<0.015
Cobalt	T-Co	0.080	<0.015	0.091	0.074	<0.015
Copper	T-Cu	0.142	<0.010	0.017	0.042	<0.010
Iron	T-Fe	3.06	0.079	0.838	6.45	0.886
Lead	T-Pb	<0.050	<0.050	<0.050	<0.050	<0.050
Lithium	T-Li	0.015	<0.015	0.114	0.111	<0.015
Magnesium	T-Mg	9.00	36.5	13.7	7.32	5.01
Manganese	T-Mn	0.197	0.023	0.378	0.466	0.037
Molybdenum	T-Mo	<0.030	<0.030	0.082	0.079	<0.030
Nickel	T-Ni	0.064	<0.020	0.018	0.046	<0.020
Phosphorus	T-P	16.5	<0.30	<0.30	0.51	4.33
Potassium	T-K	59.3	37.2	37.6	31.2	11.9
Selenium	T-Se	<0.20	<0.20	<0.20	<0.20	<0.20
Silver	T-Ag	<0.015	<0.015	<0.015	<0.015	<0.015
Sodium	T-Na	6.9	7.7	184	141	<2.0
Strontium	T-Sr	0.161	0.448	0.330	0.237	0.136
Thallium	T-Tl	<0.10	<0.10	<0.10	<0.10	<0.10
Tin	T-Sn	<0.30	<0.30	<0.30	<0.30	<0.30
Titanium	T-Ti	0.014	0.013	<0.010	0.031	<0.010
Tungsten	T-W	<0.10	<0.10	<0.10	<0.10	<0.10
Vanadium	T-V	<0.030	<0.030	0.037	0.124	<0.030
Zinc	T-Zn	0.411	0.719	0.489	0.334	0.149
Extractables						
Oil and Grease		6	1	5	3	<1

< = Less than the detection limit indicated.
Results are expressed as milligrams per dry kilogram except for moisture (%).

RESULTS OF ANALYSIS - Water

Parameter		T2-W	T3-W	T4-W
Physical Tests				
Conductivity umhos/cm		742	962	769
pH		8.04	7.97	8.22
Nutrients				
Ammonia Nitrogen	N	0.013	16.7	19.9
Nitrate Nitrogen	N	31.2	6.47	0.230
Total Phosphorus	P	0.376	0.259	1.92

< = Less than the detection limit indicated.
Results are expressed as milligrams per dry kilogram except for moisture (%).

Parameter		T2-T	T3-T	T4-T
Total Metals				
Aluminum	T-Al	<0.20	<0.20	2.08
Antimony	T-Sb	<0.20	<0.20	<0.20
Arsenic	T-As	<0.20	<0.20	<0.20
Barium	T-Ba	0.055	0.055	0.065
Beryllium	T-Be	<0.005	<0.005	<0.005
Bismuth	T-Bi	<0.10	<0.10	<0.10
Cadmium	T-Cd	<0.010	<0.010	<0.010
Calcium	T-Ca	133	46.3	18.2
Chromium	T-Cr	<0.015	<0.015	<0.015
Cobalt	T-Co	<0.015	0.047	0.054
Copper	T-Cu	<0.010	<0.010	0.017
Iron	T-Fe	0.267	0.483	2.81
Lead	T-Pb	<0.050	<0.050	<0.050
Lithium	T-Li	<0.015	0.082	0.085
Magnesium	T-Mg	14.5	9.77	5.77
Manganese	T-Mn	0.018	0.213	0.210
Molybdenum	T-Mo	<0.030	0.041	0.080
Nickel	T-Ni	<0.020	0.022	0.037
Phosphorus	T-P	0.34	<0.30	0.66
Potassium	T-K	10.7	20.9	19.1
Selenium	T-Se	<0.20	<0.20	<0.20
Silver	T-Ag	<0.015	<0.015	<0.015
Sodium	T-Na	3.9	110	121
Strontium	T-Sr	0.206	0.203	0.201
Thallium	T-Tl	<0.10	<0.10	<0.10
Tin	T-Sn	<0.30	<0.30	<0.30
Titanium	T-Ti	<0.010	<0.010	0.031
Tungsten	T-W	<0.10	<0.10	<0.10
Vanadium	T-V	<0.030	<0.030	0.055
Zinc	T-Zn	0.209	0.603	0.240
Extractables				
Oil and Grease		<1	<1	8

< = Less than the detection limit indicated.
Results are expressed as milligrams per dry kilogram except for moisture (%).

End of Report

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SATURATED HYDRAULIC CONDUCTIVITY

Soilcon Job 92-016
EVS Consulting
Hue Hamilton

	Ksat (cm/hr)	Ksat (in/hr)
T1 - A	13.962	5.4967
T1 - B	17.601	6.9297
T1 - C	13.222	5.2056
T2 - A	24.712	9.7292
T2 - B	26.013	10.2413
T2 - C	12.583	4.9538
T3 - A	0.217	0.0854
T3 - B	0.114	0.0448
T3 - C	1.083	0.4264
T4 - A	0.470	0.1852
T4 - B	0.980	0.3859
T4 - C	2.024	0.7970

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PHYSICAL PROPERTY PACKAGE

Job 92-16 EVS Consultants		Volumetric Water Content % 5	 10	 33 J/Kg	 50	 100	Bulk Density kg/m3	Partic Density kg/m3	Effective Porosity % vol	Campbell b	Air Entry Tension J/kg
1	T1-A	33.9	31.3	29.1	24.7	23.0	1722	2632	34.6	12.4	6.9
2	T1-B	33.3	28.8	27.2	22.9	20.0	1753	2645	33.7	9.8	5.2
3	T1-C	30.0	26.6	21.4	21.2	17.9	1717	2624	34.6	8.2	2.9
4	T2-A	42.3	37.7	36.0	31.1	27.8	903	2384	62.1	5.1	10.0
5	T2-B	35.4	32.1	30.6	26.1	22.9	868	2359	63.2	3.7	8.2
6	T2-C	38.0	33.5	32.0	26.6	23.5	987	2397	58.8	4.4	8.1
7	T3-A	37.3	27.0	22.6	17.7	15.6	1194	2409	50.4	3.7	5.4
8	T3-B	39.9	36.9	31.7	25.6	21.1	1163	2376	51.1	5.4	7.5
9	T3-C	40.0	36.5	31.9	26.0	21.3	1165	2365	50.7	5.6	7.6
10	T4-A	25.7	21.2	17.0	11.2	10.9	1190	2324	48.8	2.9	3.8
11	T4-B	33.0	27.8	23.9	21.4	19.6	1170	2342	50.0	4.0	6.1
12	T4-C	27.3	23.1	17.7	13.8	13.3	1207	2401	49.7	3.0	4.4

Please note that saturated hydraulic conductivities may not be accurate, samples were saturated for 10 days however saturation still was not complete, due to the hydrocarbon coating.

SUNCOR Dry Land Reclamation Study via Leachate Columns

3544-29.1

Date	Time	Maximum Temp (°C)	Minimum Temp (°C)	Present Temp (°C)	Mean of Max–Min (°C)	Comments	Initials
10 MAR 92	1030	20.5	13	18	17.3		MGS
11 MAR 92	1700	20	13	13	[illegible]		MGS
12 MAR 92	0950	18	13	18	15.5		MGS
[illegible]	14:00	19.5	15	18	17.3		[illegible]
[illegible]	[illegible]	21	16	17.5	18.5		SH
16/3/92	1250H	22	15.5	17.5	17.6		[illegible]
[illegible]	[illegible]	[illegible]	16	13	16.0		MGS
[illegible]	[illegible]	13	14	13	15.5	[illegible]	MGS
18 MAR 92	11	18	16	17	17		MGS
[illegible]	[illegible]	20	16.5	20			[illegible]
20 MAR 92	14:10	20	16	18	18		SH
21/3/92	1620H	20.5	16.5	20	18		[illegible]
22/3/92	1800H	20	15	18	17.5		[illegible]
23 MAR 92	1200	20	16	18	18		MGS
25 MAR 92	1440	21	16	20			MGS

[illegible]

12-Mar-92

[illegible]

SUNCOR Dry Land Reclamation Study via Leachate Columns

3/144-19.1

	Date	11MAR92	12MAR92	13 Mar 92	14 Mar 92	15/3/92	16 Mar 92	[illegible]	18 Mar 92	19 Mar 92	20 Mar	21/3/92	22/3/92
	Day	1	2	3	4	5	[illegible]	[illegible]	[illegible]	9	10	11	12
	Time	1500	1100	14:00	[illegible].15	1250H	[illegible]	1:20	1400	15:15	2:30	1620H	1500H
Approx. Vol. of Leachate Collected (mL)	T1 - A	1500 mL	1300	550	300ml	750	900		500	700	300	300	900
	T1 - B	600	1250	700	550	600	600		400	800	500	550	700
	T1 - C	2000	1500	600	550	500	300		[illegible]	700	600	700	600
	T2 - A	2000	800	1000	700	500	700		500	450	750	800	500
	T2 - B	2000	1000	700	450	450	700		[illegible]	600	900	500	500
	T2 - C	1700	1000	450	950	600	700		[illegible]	550	500	900	500
	T3 - A	200	200	150	100	200	150		[illegible]	150	150	100	100
	T3 - B	200	250	200	200	200	150			150	150	100	150
	T3 - C	300	150	200*	100	150	200			200	200	100	200
	T4 - A	150	300	100	200	150	100			200	150	150	2500
	T4 - B	400	150	200	200	200	200			100	250	200	150
	T4 - C	300	250	200	150	100	200			150	200	150	100
Initials		MGS	SHH	[illegible]	IW	MGS/[illegible]	MGS			KXK/SHH	IW	IW	IN/MGS

Rainfall Rates												
Vol/min/column (mL/min)	250	190	190	190	190	[illegible]	0	190	190	190	190	190
Duration (min)	10	2	2	2	2	[illegible]	0	2	2	2	2	2
# of events	1	3	2	2	2		[illegible]	2	2	2	2	2
			4	4	4					4	4	4

*lost -

SUNCOR **Dry Land Reclamation Study via Leachate Columns**

3/144-19.1

	Date	23MAR92	24	25		collected.							
	Day	13 (mon)	14	15		TOTAL for Rainfall							
	Time	1300		1900		Days	1-6		Days 8-13				
Approx. Vol.	T1 - A	600					5300		3700				
of	T1 - B	500					4300		3450				
Leachate	T1 - C	400					3450		3650				
Collected													
(mL)	T2 - A	600					5700		3600				
	T2 - B	600					5300		3550				
	T2 - C	500					5400		3550				
	T3 - A	100					1000		700				
	T3 - B	100					1250		800				
	T3 - C	150					900		950				
	T4 - A	100					1000		950				
	T4 - B	150					1300		1000				
	T4 - C	150					1200		850				
Initials		MGS					MGS		MGS				

Rainfall Rates												
Vol/min/column (mL/min)	190 mL/min											
Duration (min)	2											
# of events	2											

APPENDIX 2

BIOASSAY RESULTS

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APR 6 1992

Mr. Hugh Hamilton/ Mr. Mike Shum
E.V.S. Consultants
195 Pemberton Avenue
N. Vancouver, B.C. V7P 2R4

31 Mar. 1992

MICROTOX BIOASSAY RESULTS

SAMPLE ID: 3/144-19.1
SAMPLE DATE: 11, 18, 25 March 1992
DATE RECEIVED: 31 Mar. 1992
DATE TESTED: 31 Mar. 1992

METHODS

The Microtox bioassay measures toxicity based on light emission from a bioluminescent bacteria in the presence or absence of a toxicant. The bacteria are exposed to different concentrations of a sample and the light loss over time is recorded; the EC_{50} is the concentration of sample causing a 50% reduction in bioluminescence.

RESULTS

Sample ID	EC_{50}
11 MARCH 1992:	
P-T1-POOL	>100%
P-T2-POOL	>100%
P-T3-POOL	>100%
P-T4-POOL	>100%
18 MARCH 1992:	
T1-START-POOL	>100%
T2-START-POOL	>100%
T3-START-POOL	>100%
T4-START-POOL	>100%
25 MARCH 1992:	
T1-END-POOL	>100%
T2-END-POOL	>100%
T3-END-POOL	>100%
T4-END-POOL	>100%

Bioassays are performed on the Beckman Model 2055 Microtox Toxicity Analyzer System using the methods described in the "Beckman Microtox System Operating Manual", 1982.

BEAK CONSULTANTS LIMITED

Marian Zazzi
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7 Apr. 1992

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The following numbers were the recorded light levels for the bacteria exposed to the samples at different concentrations. The 100% test procedure was followed, which entails adding the bacteria directly to the sample, therefore there were no initial light levels. Light levels at 5, 15 and either 25 or 30 minutes after exposure of bacteria to sample were recorded.
Concentrations are in percent.
"B" indicates a blank.

Sample: P-T1-POOL

CONC.	5 min	15 min	30 min
B	92	77	77
B	90	74	74
22.75	102	88	84
22.75	99	86	83
45.4	95	84	79
45.4	103	91	86
90.9	93	73	67
90.9	92	73	68

5 min EC50: >100%
15 min EC50: >100%
30 min EC50: >100%

Sample: P-T2-POOL

CONC.	5 min	15 min	30 min
B	92	83	87
B	96	82	82
22.75	112	107	110
22.75	125	108	115
45.4	128	123	120
45.4	138	129	124
90.9	144	138	130
90.9	147	139	133

5 min EC50: >100%
15 min EC50: >100%
30 min EC50: >100%

Sample: P-T3-POOL

CONC.	5 min	15 min	30 min
B	100	93	96
B	97	90	91
22.75	110	91	90
22.75	110	93	94
45.4	102	87	87
45.4	103	87	87
90.9	89	77	76
90.9	89	78	77

5 min EC50: >100%

15 min EC50: >100%

20 min EC50: >100%

Sample: P-T4-POOL

CONC.	5 min	15 min	30 min
B	91	84	86
B	91	84	86
22.75	97	82	77
22.75	94	79	75
45.4	87	74	70
45.4	90	76	71
90.9	73	62	57
90.9	72	60	55

5 min EC50: >100%

15 min EC50: >100%

30 min EC50: >100%

Sample: T1-START-POOL

CONC.	5 min	15 min	30 min
B	91	83	85
B	88	80	83
22.75	110	102	96
22.75	111	109	108
45.4	121	112	105
45.4	121	114	107
90.9	115	108	99
90.9	106	98	91

5 min EC50: >100%

15 min EC50: >100%

30 min EC50: >100%

Sample: T2-START-POOL

CONC.	5 min	15 min	25 min
B	89	81	82
B	86	79	82
22.75	107	108	107
22.75	103	104	103
45.4	113	116	115
45.4	107	111	110
90.9	123	126	123
90.9	108	116	114

5 min EC50: >100%

15 min EC50: >100%

25 min EC50: >100%

Sample: T3-START-POOL

CONC.	5 min	15 min	25 min
B	90	85	84
B	89	83	83
22.75	110	99	93
22.75	113	103	97
45.4	114	107	100
45.4	111	99	93
90.9	115	104	93
90.9	115	104	93

5 min EC50: >100%

15 min EC50: >100%

25 min Ec50: >100%

Sample: T4-START-POOL

CONC.	5 min	15 min	25 min
B	87	81	83
B	84	79	81
22.75	108	96	91
22.75	113	100	95
45.4	103	89	84
45.4	101	90	84
90.9	82	69	62
90.9	81	68	59

5 min EC50: >100%

15 min EC50: >100%

25 min EC50: >100%

Sample: T1-END-POOL

CONC.	5 min	15 min	25 min
B	92	76	73
B	91	75	71
22.75	106	87	81
22.75	116	95	88
45.4	116	95	87
45.4	113	93	86
90.9	133	112	101
90.9	117	98	89

5 min EC50: >100%

15 min EC50: >100%

25 min EC50: >100%

Sample: T2-END-POOL

CONC.	5 min	15 min	25 min
B	81	89	90
B	84	94	93
22.75	97	108	105
22.75	96	108	102
45.4	104	117	110
45.4	108	122	115
90.9	110	120	111
90.9	107	120	111

5 min EC50: >100%

15 min Ec50: >100%

25 min EC50: >100%

Sample: T3-END-POOL

CONC.	5 min	15 min	25 min
B	91	84	84
B	90	83	83
22.75	105	93	92
22.75	108	95	96
45.4	111	101	102
45.4	107	97	97
90.9	109	99	98
90.9	116	104	97

5 min EC50: >100%

15 min EC50: >100%

25 min EC50: >100%

Sample: T4-END-POOL

CONC.	5 min	15 min	25 min
B	83	71	70
B	85	74	75
22.75	112	96	91
22.75	117	102	96
45.4	116	99	92
45.4	116	100	93
90.9	98	80	71
90.9	101	83	75

5 min EC50: >100%

15 min EC50: >100%

25 min EC50: >100%

Bioassays are performed on the Beckman Model 2055 Microtox Toxicity Analyzer System using the methods described in the "Beckman Microtox System Operating Manual", 1982.

BEAK CONSULTANTS LIMITED

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Report on Bioassessment Extracts of 12 Soil Samples

Job # BQ02292

Prepared by
Martin Samoiloff, PhD
Senior Scientist

for

High Hamilton, PhD
EVS Consultants
Vancouver, BC

30 March, 1992

Report on Bioassessment Extracts of 12 Soil Samples

Introduction

BioQuest International received 12 soil samples by courier on March 20, 1992. Each soil sample was homogenized, and two subsamples were taken from each homogenate. One subsample of each sample was extracted in methanol (2:1 volume/weight), and the other subsample was extracted with ultrapure water (2:1 volume/weight). Extractions were carried out for 24-hours at 21° Celsius. The extracts were tested for toxicity using the nematode test, a sensitive indicator of toxicity.

The methanol extracts were tested for toxicity at working concentrations of 3% and 1%, diluted in M9-Y medium. The water extracts were tested for toxicity at working concentrations of 1%, 10%, and 50%, diluted in M9-Y medium.

The Nematode Test

The nematode test measures the survival, growth, and maturation of 100 newborn larvae of *Panagrellus redivivus* over a 96-hour exposure period. At birth the animals are approximately 0.3 mm in length, but reach the adult stage and a length of approximately 1.5 mm over a 96-hour growth period. Under very toxic conditions, the animals die. Under less toxic conditions many animals survive, but will fail to grow. Under still less toxic conditions, the animals will survive and grow, but will fail to fully mature into adults.

BioQuest International performs the nematode test following the methods of Samoiloff[1] (1990). Ten newborn larvae are placed in each of ten 2 mL Autoanalyzer cups containing the test extract diluted in M9-Y medium. For methanol extracts, a control population of 10 sets of ten newborn animals are placed in 3% methanol in M9-Y medium, and another control population was set up in 1% methanol in M9-Y medium. For aqueous extracts, control populations are set up in 1%, 10%, and 50% ultrapure water diluted in M9-Y medium. The M9-Y medium acts as both a buffer and a source of nutrients. The nematode test requires at least 50% M9-Y medium. The test and control animals are allowed to grow for 96 hours.

After the growth period, the number of survivors in each group is counted and the size of each animal recorded. From these numbers, four indicators of the health of the test population is calculated:

- **Survival** is the number of test animals that survive, expressed as a percentage of survival of control animals.

---

[1] Samoiloff, 1990. The nematode toxicity assay using *Panagrellus redivivus*. Toxicity Assessment 5:309-318.

- **Growth** is the percentage of test animals that grow to more than 0.5 millimeters during the growth period, expressed as a percentage of growth in the control population.
- **Maturation** is the percentage of those test animals that grew to more than 0.5 mm that continue growth to the adult stage, expressed as a percentage of this value in the control population.
- **Fitness** is a weighted mean of the survival, growth, and maturation of the test population, expressed as a proportion of this value for the control population.

In general, a fitness less than 95 or more than 105 indicates an effect from the tested sample. A fitness below 95 indicates toxicity in the test sample. A fitness greater than 105 indicates stimulation due to an excess of nutrients in the test sample.

The observed effects can be divided into seven qualitative categories:

No detected effect:	No effect on survival growth or maturation
Stimulation:	Fitness greater than 105
Slight toxicity:	Inhibition of maturation, fitness greater than 90
Some toxicity:	Inhibition of maturation, no effect on growth or survival, fitness less than or equal to 90
Moderate toxicity:	Significant inhibition of growth, no effect on survival
High toxicity:	Significant lethality, but more than 20% survival
Extreme toxicity:	Less than 20% survival.

Tests are performed using the genetically homogeneous strain *bq1* of *Panagrellus redivivus* at 21° Celsius under conditions of 16 hours light and 8 hours darkness. Strain *bq1* was selected for high sensitivity to toxicants. The sensitivity of stocks is checked every 14 days using a zinc sulfate as a reference toxicant.

Tests are repeated if the following nematode test quality control criteria are met:

a. more than 50% of control animals reach the adult stage.

b. more than 90% of the control population survives

c. there is no extensive microbial contamination in the control tests.

All tests reported here met the above criteria.

Results

The results of the nematode test on methanol extracts from the 12 soil samples are shown in Table 2. The results of the nematode test on water extracts from the 12 soil samples are shown in Table 2.

Table 1. Results of the nematode toxicity test on 3% and 1% methanol extracts from the 12 soil samples. The numbers show the percent survival, growth, maturation, and fitness relative to controls.

Sample		Survival	Growth	Maturation	Fitness	Comment
T1-A	3%	100 -	100 -	102 -	100 -	No detected effect
	1%	97 -	96 -	96 -	97 -	No detected effect
T1-B	3%	98 -	102 -	104 -	100 -	No detected effect
	1%	99 -	99 -	100 -	99 -	No detected effect
T1-C	3%	100 -	95 -	94 -	98 -	No detected effect
	1%	98 -	104 -	90 -	99 -	No detected effect
T2-A	3%	93 -	109 -	109 -	100 -	No detected effect
	1%	97 -	105 -	87 -	98 -	No detected effect
T2-B	3%	103 -	99 -	81 -	99 -	No detected effect
	1%	98 -	100 -	96 -	98 -	No detected effect
T2-C	3%	101 -	98 -	117 -	102 -	Marginal stimulation
	1%	97 -	101 -	93 -	98 -	No detected effect
T3-A	3%	98 -	57 I	83 i	84 I	Moderate toxicity
	1%	98 -	92 -	89 -	95 -	No detected effect
T3-B	3%	98 -	78 I	102 -	93 I	Moderate toxicity
	1%	99 -	86 -	83 i	93 i	Slight toxicity
T3-C	3%	94 -	68 I	111 -	89 I	Moderate toxicity
	1%	99 -	105 -	104 -	101 -	No detected effect
T4-A	3%	95 -	74 I	57 i	84 I	Moderate toxicity
	1%	98 -	102 -	93 -	98 -	No detected effect
T4-B	3%	101 -	102 -	96 -	101 -	No detected effect
	1%	97 -	100 -	93 -	97 -	No detected effect
T4-C	3%	98 -	99 -	115 -	101 -	No detected effect
	1%	98 -	93 -	96 -	96 -	No detected effect

I	indicates significant inhibition of growth
i	indicates significant inhibition of maturation
-	indicates no significant effect

Table 2. Results of the nematode toxicity test on 50%, 10%, and 1% water extracts from the 12 soil samples.

Sample		Survival	Growth	Maturation	Fitness	Comment
T1-A	50%	22 L	28 I	0 i	21 L	High toxicity
	10%	88 -	79 I	85 i	85 I	Moderate toxicity
	1%	99 -	100 -	97 -	99 -	No detected effect
T1-B	50%	21 L	17 I	0 i	17 L	High toxicity
	10%	95 -	82 I	89 i	90 I	Moderate toxicity
	1%	98 -	104 -	93 -	99 -	No detected effect
T1-C	50%	76 L	60 I	33 i	65 L	High toxicity
	10%	99 -	101 -	105 -	100 -	No detected effect
	1%	100 -	99 -	101 -	100 -	No detected effect
T2-A	50%	14 L	35 I	0 i	18 L	High toxicity
	10%	92 -	92 -	74 i	89 i	Some toxicity
	1%	101 -	102 -	90 -	100 -	No detected effect
T2-B	50%	19 L	45 I	25 i	27 L	High toxicity
	10%	93 -	97 -	80 i	92 i	Slight toxicity
	1%	100 -	99 -	93 -	99 -	No detected effect
T2-C	50%	14 L	43 I	70 i	30 L	High toxicity
	10%	97 -	84 -	68 i	89 i	Some toxicity
	1%	101 -	108 -	106 -	104 -	Marginal stimulation
T3-A	50%	0 L	0 I	0 i	0 L	Extreme toxicity
	10%	73 L	37 I	20 i	55 L	High toxicity
	1%	100 -	101 -	97 -	100 -	No detected effect
T3-B	50%	0 L	0 I	0 i	0 L	Extreme toxicity
	10%	96 -	71 I	18 i	78 I	Moderate toxicity
	1%	101 -	102 -	103 -	102 -	No detected effect
T3-C	50%	0 L	0 I	0 i	0 L	Extreme toxicity
	10%	92 -	60 I	9 i	71 I	Moderate toxicity
	1%	96 -	102 -	80 -	95 -	No detected effect
T4-A	50%	0 L	0 I	0 i	0 L	Extreme toxicity
	10%	73 L	21 I	0 i	48 L	High toxicity
	1%	96 -	102 -	90 -	97 -	No detected effect
T4-B	50%	0 L	0 I	0 i	0 L	Extreme toxicity
	10%	27 L	4 I	0 i	17 L	High toxicity
	1%	99 -	106 -	72 i	97 -	Slight toxicity
T4-C	50%	0 L	0 I	0 i	0 L	Extreme toxicity
	10%	28 L	12 I	0 i	19 L	High toxicity
	1%	98 -	94 -	86 -	95 -	No detected effect

L	indicates significant lethality
I	indicates significant inhibition of growth
i	indicates significant inhibition of maturation
-	indicates no significant effect

Results(cont)

Of the methanol extracts, four (T3-A, T3-B, T3-C, and T4-A) showed moderate toxicity at 3%, but only one of these (T3-B) showed slight toxicity at 1%. One methanol extract (T2-C) had a marginally stimulatory effect.

Of the water extracts, all showed some degree of lethal effect at 50%. At 50%, six water extracts (T3-A, T3-B, T3-C, T4-A, T4-B, and T4-C) showed extreme toxicity, killing all exposed animals. The remainder of the 50% water extracts showed high toxicity, but permitted some survival of exposed animals.

At a 10% dilution, eleven water extracts showed toxic effects. Four water extracts (T3-A, T4-A, T4-B, T4-C) had lethal effects at 10%. Four water extracts (T1-A, T1-B, T3-B, and T3-C) inhibited growth at 10%. Three water extracts (T2-A, T2-B, and T2-C) only had an inhibitory effect on maturation at 10%. One water extract (T1-C) had no detected effect at 10%.

Only one water extract (T4-B) had a toxic effect at 1%. This extract inhibited maturation by 28%. The water extract from sample T2-C had a slightly stimulatory effect at 1%.

Prepared by

Martin Samoiloff

Martin Samoiloff, PhD
Senior Scientist

30 March, 1992

TOXICITY TEST
Hyalella azteca

EVS CONSULTANTS

HYALELLA AZTECA SEDIMENT BIOASSAYS
WATER QUALITY MONITORING

Water Quality Instruments Used
D.O. Meter YSI 57 #2
pH Meter Fisher 119 #8
Conductivity YSI SCT ~~33~~ #2
Temperature Thermometer.

Client : Suncor
9/144-17 EVS Project No. : ~~3/144-19.1~~ BK
EVS W.O. No.:
Day 0 : March 20/92
Day 10 : March 30/92
Source of Test Species : In House

SAMPLE ID	TEMPERATURE (°C) BK							CONDUCTIVITY (µmhos/cm) BK							DISSOLVED OXYGEN (mg/L) BK							pH							Hardness (mg/L)	
	0	1	2	3/6	4/8	5/10	6/12	0	1	2	3/6	4/8	5/10	6/12	0	1	2	3/6	4/8	5/10	6/12	0	1	2	3/6	4/8	5/10	6/12	0	10
CONTROL	22	23.5	23.5	22.5	24	24	23	235	220	210	220	230	260	250	8.3	86	88	8.2	8.0	7.1	8.5	7.7	78	78	7.6	7.8	7.9	7.9	81	83
T1-A	22	23.5	24	22.5	24	24	23	245	250	235	250	260	270	270	8.3	6.9[1]	86	8.0	7.6	7.6	8.4	7.7	73	78	7.6	7.7	7.7	7.8		
T1-B	22	23.5	24	23.5	24	24	23	240	215	225					8.3	78	86					7.8	77	79	~~7.8~~ BK					
T1-C	22	23.5	24	23.5	24	24	23	240	215	210					8.4	79	83					7.8	78	79						
T2-A	22	23.5	24	23.5	24	24	23	300	310	315	330	350	370	370	9.2	77	83	8.0	7.3	7.5	8.2	7.9	76	79	7.5	7.7	7.8	8.0		
T2-B	22	23.5	24	23.5	24	24	23	295	310	315					8.2	78	84				7.9	8.0	77	78						
T2-C	22	23.5	24	23.5	24	24	23	325	350	355					8.0	6.6[1]	82					7.9	75	78						
T3-A	22	23.5	24	23.5	24	24	23	290	330	340	355	390	420	415	8.1	82	83	8.0	7.6	7.7	8.1	8.0	80	79	7.8	8.0	8.1	8.2		
T3-B	22	23.5	24	23.5	24	24	23	295	340	315					8.2	81	83					8.0	80	81						
T3-C	22	23.5	24	23.5	24	24	23	290	330	310					8.4	81	82					8.0	80	81						
T4-A	22	23.5	24	23.5	24	24	23	360	365	370	375	405	440	435	5.4	75	74	7.6	7.0	7.3	7.8	7.7	78	80	7.7	8.1	8.1	8.1		
T4-B	22	23.5	24	23.5	24	24	23								5.4	74	72					7.6	77	80						
T4-C	22	23.5	24	23.5	24	24	23								5.4	6.1[1]	73					7.6	76	79						
Technician	BI	WW	JW	BK	BK	BK	AT	BK	WW	WW	BK	BK	BK	AT	BK	JW	JW	BK	BK	BK	AT	BK	WW	WW	BK	BK	BK	AT	BK	BI

Comments/Adjustments Made : 1 ADJUSTED AERATION

All entries are to be made with black, ball-point pen. Cross out errors with a single line and initial and date corrections. Do not use "White-Out".

EVS CONSULTANTS

HYALELLA AZTECA SEDIMENT BIOASSAYS
WATER QUALITY MONITORING

Water Quality Instruments Used

D.O. Meter YSI Model 57 #2
pH Meter Fisher 119 #8
Conductivity YSI Model 33 #2
Temperature Thermometer

BK
Client : ~~Golder~~ Suncor
9/144-17 EVS Project No. : ~~9/540-02~~ B
EVS W.O. No.: ~~3/144-19.1~~
Day 0 : March 20, 1992
Day 10 : March 30, 1992
Source of Test Species : In House

SAMPLE ID	TEMPERATURE (°C)							CONDUCTIVITY (µmhos/cm)							DISSOLVED OXYGEN (mg/L)							pH							Hardness (mg/L)	
	7 ~~0~~	8 ~~2~~	9 ~~4~~	10 ~~6~~	8	10	12	230 ~~0~~	2	4	6	8	10	12	0	2	4	6	8	10	12	0	2	4	6	8	10	12	0	10
Control	24	24	24	23				~~255~~	250	230	260				8.4	82	81	8.1				7.9	79	79	7.8					
T1-A	24	24	24.5	23				255	275	299	275				8.2	82	81	8.0				7.9	80	80	7.9					
T1-B	24	24	24.5	23							270							7.9							7.9					
T1-C	24	24	24.5	23							285							7.8							8.0					
T2-A	24	24	24.5	23				365	380	310	390				7.6	81	81	7.9				7.9	82	83	8.2					
T2-B	24	24	24.5	23							380							7.7							8.2					
T2-C	24	24	24.5	23							450							7.8							8.2					
T3-A	24	24	24.5	23				400	420	410	440				7.9	79	80	~~7.8~~ 7.6	AT			AT ~~7.9~~	82	82	8.2					
T3-B	24	24	24.5	23							435							7.4				8.3			8.7					
T3-C	24	24	24.5	23							440							7.6							8.3					
T4-A	24	24	24.5	23				420	445	425	450				7.4	76	73	6.8				8.0	80	80	8.1					
T4-B	24	24	24.5	23							400							6.2							7.3					
T4-C	24	24	24.5	23							440							6.9							8.1					
Technician	AT	IW	IW	BK				AT	IW	IW	BK				AT	IW	IW	BK				AT	IW	IW	BK					

Comments/Adjustments Made :

All entries are to be made with black, ball-point pen. Cross out errors with a single line and initial and date corrections. Do not use "White-Out".

Golder/Suncor
91540-02 91144-17
WO # 920098

EVS CONSULTANTS

ALKALINITY/HARDNESS MEASUREMENTS

Sample I.D.	Alkalinity (mg/L as $CaCO_3$)					Hardness (mg/L as $CaCO_3$)			
	Sample Volume	Initial H_2SO_4 Volume	Volume to pH 4.5	Total Volume to pH 4.2	Alkalinity	Sample Volume	Initial EDTA Volume	Final EDTA Volume	Hardness
CONTROL d0	~~100ml~~					100ml	0	8.1	81
control d10						100ml	5.6	13.9	83
A control Ref Tox	0 hr					100ml	2.3	10.3	80
B Cont Ref Tox	0 hr					100ml	10.3	18.3	80
Cont Ref Tox	~~9~~48 hr					100ml	0	8.1	81
B Cont Ref Tox	48 hr					100ml	8.1	16.2	81
						BIC	BIC	BIC	BIC

EVS CONSULTANTS
Hyalella azteca SEDIMENT BIOASSAY - WATER QUALITY AT DAY 10

Client Suncor

EVS Project Number ~~3/444-19.1~~ BK 9/144-17

EVs W.O. No.

Day 0 March 20/92

Day 10 March 30/92

Sample I.D.	Rep.	pH	Dissolved Oxygen (mg/L)	Temp. (°C)	Cond. (µmhos/cm)	Comments
CONTROL	A	8.0	7.8	23	225	
	B	8.1	7.8	23	235	
	C	8.0	7.9	23	235	
	D	8.0	7.8	23	230	
	E	8.0	7.8	23	250	
T1	A	7.9	8.0	23	275	
	B	7.9	7.9	23	270	
	C	8.0	7.8	23	285	
T2	A	8.2	7.9	23	390	
	B	8.2	7.7	23	380	
	C	8.2	7.8	23	450	
T3	A	8.2	7.6	23	440	
	B	8.2	7.4	23	435	
	C	8.3	7.6	23	440	
T4	A	8.1	6.8	23	450	
	B	7.8	6.2	23	400	
	C	8.1	6.9	23	440	
Technician		BK	BK	BK	BK	

Water Quality Instruments Used

pH Fisher 119 #8 D.O. YSI 57 #2 Conductivity SCT 33 #2

EVS CONSULTANTS
ACUTE TOXICITY TEST DATA

SAMPLE I.D. Zn Reference Toxicant
DATE COLLECTED Dec 5/91 Zn Stock
TEST DATE/TIME May 23/92
NO. ORGANISMS/VOLUME 10/100 ml

Page No. ___
PROJECT NAME Golder/Suncor
EVS PROJECT NO. 91540-02/~~3/144-1~~ BK
WORK ORDER NO. 920098 3/144-1
TEST SPECIES Hyalella azteca
SOURCE & BATCH In house culture

CONC. ug/L	PERCENT SURVIVAL (1 to 96 hours)							DISSOLVED OXYGEN (mg/L)					TEMPERATURE (°C)					pH					COND. (μmhos/cm)		ALK. (mg/L)		HARD. (mg/L)	
	1	2	4	~~24~~ 48	48	72	96	0	24	48	72	96	0	24	48	72	96	0	24	48	72	96	0	~~96~~ 48	0	96	0	96
CONTROL A				100				8.8		8.1			22		24			7.5		7.5			115	170			80	81
CONTROL B				100				8.8		8.1			22		24			7.6		7.7			115	180			80	81
3.3 BK ~~0.33~~ A				100				8.8		8.2			22		24			7.6		7.7			135	145				
3.3 BK ~~0.33~~ B				60*				8.8		8.2			22		24			7.6		7.7			135	145				
10.0 BK ~~1.0~~ A				80				8.8		8.0			22		24			7.6		7.7			130	145				
10.0 BK ~~1.0~~ B				90				8.8		8.1			22		24			7.6		7.7			130	140				
33.0 BK ~~3.3~~ A				90				8.8		8.1			22		24			7.6		7.7			130	145				
33.0 BK ~~3.3~~ B				90				8.8		8.0			22		24			7.6		7.7			130	145				
Technician				BK				BK		BK			BK		BK			BK		BK			BK	BK				

SAMPLE DESCRIPTION

COMMENTS * only 6 animals * no bodies in many, only have started with 6 BK

TEST SET UP BY: BJK DATA VERIFIED BY: DATE VERIFIED:

EVS ENVIRONMENT CONSULTANTS

EVS CONSULTANTS
ACUTE TOXICITY TEST DATA

Page No. ___

SAMPLE I.D. Zn Reference toxicant
DATE COLLECTED Dec 5/91 Zn Stock
TEST DATE/TIME March 23,1992
NO. ORGANISMS/VOLUME 10/100ml

PROJECT NAME Golder/Suncor
EVS PROJECT NO. 91540-02/~~3/144-19~~
WORK ORDER NO. 920098 9/144-1
TEST SPECIES Hyalella azteca
SOURCE & BATCH In house culture

CONC.	PERCENT SURVIVAL (1 to 96 hours)							DISSOLVED OXYGEN (mg/L)					TEMPERATURE (°C)					pH					COND. (μmhos/cm)		ALK. (mg/L)		HARD. (mg/L)	
	1	2	4	24	48	72	96	0	24	48	72	96	0	24	48	72	96	0	24	48	72	96	0	96	0	96	0	96
100.0 BK ~~10.0~~ A					60			8.8		8.2			22	BK ~~24~~	24			7.6		7.7			135	150				
100.0 BK ~~10.0~~ B					60			8.8		8.0			22	~~24~~	24			7.6		7.7			135	145				
330.0 BK ~~33.0~~ A					0			8.8		8.0			22	~~24~~	24			7.6		7.7			135	145				
330.0 BK ~~33.0~~ B					0			8.6		8.0			22	~~2c~~	24			7.5		7.7			140	150				
1000 BK ~~100~~ A					0			8.8		8.0			22		24			7.3 ~~7.~~ BK		7.4			130	150				
1000 BK 100 B					0			8.8		8.1			22		24			7.3		7.5			135	150				
Technician					BK			BK		BK			BK		BK			BK		BK			BK	BK				

SAMPLE DESCRIPTION ___
COMMENTS ___

TEST SET UP BY: BK
DATA VERIFIED BY: ___
DATE VERIFIED: ___

EVS ENVIRONMENT CONSULTANTS

```
                FILE:  Suncor
TEST:      9/144-17                         DATE:      March 23, 1992
SPECIES:   Hyalella azteca                  DURATION: 96 h
CHEMICAL:  Zn
CARRIER:   M-H water                        CARRIER CONC:

   Conc       Number      Number     Percent     Binomial
   ----       exposed     dead       dead        prob(percent)
              -------     ----       ----        ------------
  1000.00       20         20        100.0          less
   330.00       20         20        100.0          less
   100.00       20          8         40.0        25.1722
    33.00       20          2         10.0         0.0201
    10.00       20          3         15.0         0.1288
     3.30       20          4         20.0         0.5909

The binom test shows that      33.000 and     330.000 can be
used as statistically sound at 95 conf since the
actual conf level associated with these limits is     100.000

An approx LC50 is     116.009    µg/L

------RESULTS USING THE MOVING AVERAGE METHOD---------------
span       g            lc50        95% conf limits
----       -            ----        ---------------------
  5    0.097538        59.888      34.235     105.709
  4    0.086431        73.352      43.970     114.934
  3    0.086431        87.495      59.640     138.996
  2    0.076028        99.602      74.664     132.318
Probit warning:no convergence in 25 iterations
```

E.V.S. CONSULTANTS - AMPHIPOD SEDIMENT BIOASSAYS
SEDIMENT DESCRIPTION AND CHARACTERIZATION

Page No. ____

Client: Suncor
EVS Project No.: ~~2/144 - 19.1~~ Bk 9/144-17
EVS W.O. No.: ____

Day 0: March 20/92
Day 10: March 30/92

SAMPLE I.D.	COLOUR	GRAIN SIZE	SMELL	SHELLS/DEBRIS?	OTHER OBSERVATIONS
control	white	sand	NO	NO	NO
T1A, T1B, T1C	Brown	sand/silt	NO	NO	NO
T2A, T2B, T2C	Black/ Brown	sand silt	NO	lots of organic matter	NO
T3A, T3B, T3C	Black Brown	sand silt	slightly oily	NO	oil stain on jars. Oily sheen on water. Some oil blobs
T4A, T4B, T4C	Black	sand silt	Oily	NO	Thick oily blobs. Difficult to recover anything.

Be descriptive when you characterize the sediments. Colour and grain size information must be complete. If the sediment has an odour, describe the type of smell. Note any shells or debris that are present. Be sure to record anything else in the Observations section.

EVS CONSULTANTS

HYALELLA AZTECA SEDIMENT BIOASSAYS
SURVIVAL AND RECOVERY DATA

Client : Suncor
EVS Project No. : ~~3/144-19.1~~ BK 9/144-17
EVS Work Order No. : ________

Test Duration : 10 days
Day 0 : March 20/92
Technician : BJK

SAMPLE I.D.	TOTAL RECOVERED	NUMBER ALIVE	NUMBER DEAD	NUMBER MISSING	COMMENTS Pan #
Control A	10	9	1	0	21
B	10	10	0	0	22
C	9	9	0	1	23
D	10	10	0	0	24
E	10	9	1	0	25
T1 A	0	0	0	10	–
T1 B	1	1	0	9	45
T1 C	2	2	0	8	59
T2 A	2	0	2	8	–
T2 B	3	1	2	7	60
T2 C	1	1	0	9	55
T3 A	0	0	0	10	
T3 B	0	0	0	10	
T3 C	0	0	0	10	
T4 A *	0	0	0	10	* T4 samples
T4 B	0	0	0	10	all very oily.
T4 C	0	0	0	10	
	BK	BK	BK	BK	BK

Page No. ____

EVS CONSULTANTS
DRY WEIGHT DATA

Client : Suncor
EVS Project Number : ~~3/144-19.1~~ BK 9/144-17
EVS W.O. Number: ____
Balance Type/Serial Number: Sartorius

Test Type : 10 day Sediment
Test Species : Hyalella azteca
Day 0: March 20/92

Sample I.D.	Rep.	Pan No.	Pan Weight (g)	Final Weight (g) (pan + biomass)	Total Biomass (g)	Number of Survivors	Average Individual Dry Weight (mg)	Technician's Initials
CONTROL	A	21	0.9979	0.9987	0.0008	10*	0.08	BK
	B	22	0.9991	0.9996	0.0005	7*	0.07	BK
	C	23	0.9936	0.9946 ~~0.0010~~ BK	0.0010	10*	0.10	BK
	D	24	0.9988	1.0004	0.0016	10	0.16	BK
	E	25	1.0003	1.0009	0.0006	9	0.07	BK
T1	A	-	-	-	-	-	-	BK
	B	45	0.9905	0.9906	0.0001	1	0.10	BK
	C	59	0.9920	0.9925	0.0005	2	0.25	BK
T2	A	-	-	-	-	-	-	BK
	B	60	0.9919	0.9920	0.0001	1	0.10	BK
	C	-	-	-	-	-	-	BK

* - # of amphipods in pan. 1 lost during transfer to pans. For control, some animals were accidentally transferred to wrong pan. BK

f:\forms\datashts\weight.dry

Sample D 8-13 T1 B-Y

Concentration 50 %

Initiation Date Apr 6/92

E.V.S. CONSULTANTS

Daphnia magna 21 D LIFE CYCLE TEST - WATER QUALITY DATA

E.V.S. Project No. 3/144-19.1

E.V.S. Work Order No.

Parameter	Date/Day of Test																					
			Apr 8		Apr 10			Apr 13		Apr 15		17/4			Apr 20		Apr 22		Apr 24			
	0	1	②	3	④	5	6	⑦	8	⑨	10	⑪	12	13	⑭	15	⑯	17	⑱	19	20	21
Temperature (°C)	22	22.5	22	22	22	23.5	23.5	22	22	22		23	23.5	24	23	23	22	23	23	24	23.5	24
D.O. (mg/L) (old solution)			9.7		8.7			9.0		8.2		8.1 ~~8.4~~ 8.5			7.2		7.8		7.5			7.8
D.O. (mg/L) (new solution)	8.8 ↓ 5 8.1	......	9.2 ↓ 5 8.4	......	8.7			8.7		8.7		83			8.1		8.8		8.2			
pH	8.2		8.0		8.2			8.0		8.0		81			8.1		8.0		8.0			
Hardness (mg/L as $CaCO_3$)																						
Alkalinity (mg/L)																						
Conductivity (µmhos/cm)	335		300		300			300		340		340			340		340		350			

O = circle indicates solution replacement

Temperature is measured daily; dissolved oxygen is measured in old and new test solutions at each renewal; pH is measured at each renewal; other parameters are measured at the start and end of the test and at least once per week during the test.

Comments:

Sample DB-13 IIC-Y

Concentration 50 %

Initiation Date Apr 6/92

E.V.S. CONSULTANTS

Daphnia magna 21 D LIFE CYCLE TEST - WATER QUALITY DATA

E.V.S. Project No. 3/144-19.1

E.V.S. Work Order No.

Parameter	Date/Day of Test																					
			Apr 8		Apr 10			Apr 13		Apr 15		17/4			Apr 20		Apr 22		Apr 24			
	0	1	②	3	④	5	6	⑦	8	⑨	10	⑪	12	13	⑭	15	⑯	17	⑱	19	20	21
Temperature (°C)	22	22.5	22	22	22	23.5	23.5	22	22	22		23	23.5	24	23	23	22	23	23	24	23.5	24
D.O. (mg/L) (old solution)			9.5		8.8			8.4		8.2		80 83 83			7.1		7.9		7.5			8.0
D.O. (mg/L) (new solution)	8.8 ↓ 5·····→ 8.2		9.5 ↓5·····→ 8.4		8.6			8.6		8.7		83			8.1		8.8		8.2			
pH	8.2		8.0		8.2			8.1		8.0		81			8.1		8.0		8.0			
Hardness (mg/L as $CaCO_3$)																						
Alkalinity (mg/L)																						
Conductivity (µmhos/cm)	310		320		310			310		325		320			330		315		350			

O = circle indicates solution replacement

Temperature is measured daily; dissolved oxygen is measured in old and new test solutions at each renewal; pH is measured at each renewal; other parameters are measured at the start and end of the test and at least once per week during the test.

Comments:

Sample Days 8-13 • Y
Concentration 50 % (v/v)
Initiation Date Apr. 6/92

E.V.S. CONSULTANTS

***Daphnia magna* 21 D LIFE CYCLE TEST DATA**

E.V.S. Project No. 3/[illegible]-19.1
E.V.S. Work Order No.

	Date/Day of Test																				
		Apr. 8		Apr. 10			Apr. 13		Apr 15		17/4			Apr 20		Apr 22		Apr. 24			
Replicate	1	②	3	④	5	6	⑦	8	⑨	10	⑪	12	13	⑭	15	⑯	17	⑱	19	20	21
A		m		m			m		m		M			m		m		m			m
T4 A-Y		\		\			12		22		22			23		19		22			19
B		m		m			m		m		M			m		m		m			m
T4 B-Y		\		\			\		10		11			12		9		24			14
C		m		m			m		m		M			m.		m.		m.			m.
T4 C-Y		\		\			12		20		21			21		23		20			11
D																					
E																					
F																					
G																					
H																					
I																					
J																					

D = dead female *Daphnia*　　S = stressed female *Daphnia*　　M = molt　　No. = number of young born　　O = circle indicates solution replacement

Comments:

Sample D 8-13 T2 A-Y

Concentration 50 %

Initiation Date Ap. 6/92

E.V.S. CONSULTANTS

Daphnia magna 21 D LIFE CYCLE TEST - WATER QUALITY DATA

E.V.S. Project No. 3/144-17.1

E.V.S. Work Order No.

Parameter	Date/Day of Test																					
			Apr 8		Apr 10			Ap. 13		Ap. 15		17/4			Ap. 20		Ap. 22		Apr 24			
	0	1	②	3	④	5	6	⑦	8	⑨	10	⑪	12	13	⑭	15	⑯	17	⑱	19	20	21
Temperature (°C)	22	22.5	22	22	22	23.5	23.5	22	22	22		23	23.5	24	23	23	22	23	20	24	23.5	24
D.O. (mg/L) (old solution)			9.8		8.8			8.1		8.0		81 ~~84~~			7.2		7.4		7.5			7.6
D.O. (mg/L) (new solution)	8.8 65 min 8.0		9.3 65 min 8.5		8.8			8.5		8.7		84			8.0		8.8		8.2			
pH	8.2		8.1		8.3			8.2		8.1		82			8.1		8.1		8.1			
Hardness (mg/L as $CaCO_3$)																						
Alkalinity (mg/L)																						
Conductivity (µmhos/cm)	465		550		550			600		600		650			600		600		600			

O = circle indicates solution replacement

Temperature is measured daily; dissolved oxygen is measured in old and new test solutions at each renewal; pH is measured at each renewal; other parameters are measured at the start and end of the test and at least once per week during the test.

Comments:

Sample D 8-13 T2 3-Y

Concentration 50 %

Initiation Date Apr. 6/92

E.V.S. CONSULTANTS

Daphnia magna 21 D LIFE CYCLE TEST - WATER QUALITY DATA

E.V.S. Project No. 3/144-19.1

E.V.S. Work Order No.

Parameter	Date/Day of Test																					
			Apr. 8		Apr. 10			Apr. 13		Apr. 15		17/4			Apr. 20		Apr. 22		Apr. 24			
	0	1	②	3	④	5	6	⑦	8	⑨	10	⑪	12	13	⑭	15	⑯	17	⑱	19	20	21
Temperature (°C)	22	22.5	22	22	22	23.5	23.5	22	22	22		23	23.5	24	23	23	22	23	23	24	23.5	24
D.O. (mg/L) (old solution)			9.8		9.0			8.3		8.2		80			7.4		8.1		7.6			7.8
D.O. (mg/L) (new solution)	8.8 15 min → 8.0		7.5 15 min → 8.4		8.7			8.6		8.8		84			8.1		8.8		8.2			
pH	8.3		8.2		8.3			8.2		8.1		82			8.1		8.1		8.1			
Hardness (mg/L as $CaCO_3$)																						
Alkalinity (mg/L)																						
Conductivity (µmhos/cm)	450		500		600			550		600		650			700		650		650			

O = circle indicates solution replacement

Temperature is measured daily; dissolved oxygen is measured in old and new test solutions at each renewal; pH is measured at each renewal; other parameters are measured at the start and end of the test and at least once per week during the test.

Comments:

Sample D8-13 T2 C-Y
Concentration 50 %
Initiation Date Apr 6/92

E.V.S. CONSULTANTS

Daphnia magna 21 D LIFE CYCLE TEST - WATER QUALITY DATA

E.V.S. Project No. 3/144-19.1
E.V.S. Work Order No.

Parameter	Date/Day of Test																					
			Apr 8		Apr 10			Apr 13		Apr 15		17/4			Apr 20		Apr 22		Apr 24			
	0	1	②	3	④	5	6	⑦	8	⑨	10	⑪	12	13	⑭	15	⑯	17	⑱	19	20	21
Temperature (°C)	22	22.5	22	22	22	23.5	23.5	22	22	22		23	23.5	24	23	23	22	23	23	24	23.5	
D.O. (mg/L) (old solution)			10.0		9.0			8.4		8.2		80			7.1		7.8		7.4			
D.O. (mg/L) (new solution)	8.7 ↓ 5 min 8.1		9.8 ↓ 5 min 8.3		8.7			8.6		8.7		84			8.1		8.8		8.2			
pH	8.3		8.2		8.3			8.2		8.1		83			8.2		8.1		8.1			
Hardness (mg/L as $CaCO_3$)																						
Alkalinity (mg/L)																						
Conductivity (µmhos/cm)	480		500		500			500		500		550			500		500		550			

O = circle indicates solution replacement

Temperature is measured daily; dissolved oxygen is measured in old and new test solutions at each renewal; pH is measured at each renewal; other parameters are measured at the start and end of the test and at least once per week during the test.

Comments:

Sample D8-13 T3 A-Y
Concentration 50%
Initiation Date Apr 6/92

E.V.S. CONSULTANTS

Daphnia magna 21 D LIFE CYCLE TEST - WATER QUALITY DATA

E.V.S. Project No. 3/144-19.1
E.V.S. Work Order No.

Parameter	Date/Day of Test																					
			Apr 8		Apr 10			Apr 13		Apr 15		17/4			Apr 20		Apr 22		Apr 24			
	0	1	②	3	④	5	6	⑦	8	⑨	10	⑪	12	13	⑭	15	⑯	17	⑱	19	20	21
Temperature (°C)	22	22.5	22	22	22	23.5	23.5	22	22	22		23	23.5	24	23	23	22	23	23	24	23.5	24
D.O. (mg/L) (old solution)			10.3		8.9			9.3		8.3		8.1			6.9		7.7		7.5			7.0
D.O. (mg/L) (new solution)	8.6		9.4 +5.– 8.5		8.8			8.6		8.7		8.4			8.0		8.8		8.2			
pH	8.3		8.2		8.3			8.3		8.2		8.3			8.2		8.1		8.1			
Hardness (mg/L as $CaCO_3$)																						
Alkalinity (mg/L)																						
Conductivity (µmhos/cm)	750		700		700			700		650		700			700		750		800			

O = circle indicates solution replacement

Temperature is measured daily; dissolved oxygen is measured in old and new test solutions at each renewal; pH is measured at each renewal; other parameters are measured at the start and end of the test and at least once per week during the test.

Comments:

Sample 3 P-13 T3 LS B2-Y

Concentration 50 %

Initiation Date Apr 6/92

E.V.S. CONSULTANTS

Daphnia magna **21 D LIFE CYCLE TEST - WATER QUALITY DATA**

E.V.S. Project No. 3/144-19.1

E.V.S. Work Order No. ______

Parameter	Date/Day of Test																					
			Apr 8		Apr 10			Apr 13		Apr 15		17/4			Apr 20		Apr 22		Apr 24			
	0	1	②	3	④	5	6	⑦	8	⑨	10	⑪	12	13	⑭	15	⑯	17	⑱	19	20	21
Temperature (°C)	22	22.5	22	22	22	23.5	23.5	22	22	22		23	23.5	24	23	23	22	23	23	24	23.5	24
D.O. (mg/L) (old solution)			10.3		8.7			8.7		8.6		87			7.0		7.9		7.3			7.8
D.O. (mg/L) (new solution)	8.6		9.6 15— 8.4		8.8			8.6		8.6		84			8.0		8.8		8.2			
pH	8.3		8.2		8.3			8.3		8.2		82			8.1		8.1		8.1			
Hardness (mg/L as $CaCO_3$)																						
Alkalinity (mg/L)																						
Conductivity (μmhos/cm)	550		600		600			600		600		650			650		700		700			

O = circle indicates solution replacement

Temperature is measured daily; dissolved oxygen is measured in old and new test solutions at each renewal; pH is measured at each renewal; other parameters are measured at the start and end of the test and at least once per week during the test.

Comments: ______

Sample D 8-13 T3 C-Y
Concentration 50 %
Initiation Date Apr 6/92

E.V.S. CONSULTANTS

Daphnia magna 21 D LIFE CYCLE TEST - WATER QUALITY DATA

E.V.S. Project No. 3/144-19.1
E.V.S. Work Order No. ______

Parameter	Date/Day of Test																					
			Apr 8		Apr 10			Apr 13		Apr 15		17/4			Apr 20		Apr 22		Apr 24			
	0	1	②	3	④	5	6	⑦	8	⑨	10	⑪	12	13	⑭	15	⑯	17	⑱	19	20	21
Temperature (°C)	22	22.5	22	22	22	23.5	23.5	22	22	22		23	23.5	24	23	23	22	23	23	24	23.5	24
D.O. (mg/L) (old solution)			10.6		8.7			8.4		8.2		80			6.9		8.0		7.4			8.0
D.O. (mg/L) (new solution)	8.6		9.4 +5 min 8.4		8.7			8.5		8.7		84			8.0		8.8		8.2			
pH	8.3		8.2		8.3			8.3		8.1		82			8.1		8.0		8.1			
Hardness (mg/L as $CaCO_3$)																						
Alkalinity (mg/L)																						
Conductivity (µmhos/cm)	450		600		600			700		600		700			650		700		700			

O = circle indicates solution replacement

Temperature is measured daily; dissolved oxygen is measured in old and new test solutions at each renewal; pH is measured at each renewal; other parameters are measured at the start and end of the test and at least once per week during the test.

Comments: ______

Sample 28-13 T4 A-Y
Concentration 50 %
Initiation Date Apr 6/92

E.V.S. CONSULTANTS

Daphnia magna **21 D LIFE CYCLE TEST - WATER QUALITY DATA**

E.V.S. Project No. 3/144-17.1
E.V.S. Work Order No. ______

Parameter	Date/Day of Test																					
			Apr 8		Apr 10			Apr 13		Apr 15		17/4			Apr 20		Apr 22		Apr 24			
	0	1	②	3	④	5	6	⑦	8	⑨	10	⑪	12	13	⑭	15	⑯	17	⑱	19	20	21
Temperature (°C)	22	22.5	22	22	22	23.5	23.5	22	22	22		23	23.5	24	23	23	22	23	23	24	23.5	24
D.O. (mg/L) (old solution)			10.1		8.8			8.8		8.6		83			7.3		7.9		7.4			7.8
D.O. (mg/L) (new solution)	8.4		8.7 +5 min 8.4		8.7			8.7		8.6		82			8.1		8.8		8.0			
pH	8.4		8.3		8.4			8.4		8.3		83			8.3		8.3		8.2			
Hardness (mg/L as $CaCO_3$)																						
Alkalinity (mg/L)																						
Conductivity (µmhos/cm)	600		500		600			500		550		550			600		600		650			

O = circle indicates solution replacement

Temperature is measured daily; dissolved oxygen is measured in old and new test solutions at each renewal; pH is measured at each renewal; other parameters are measured at the start and end of the test and at least once per week during the test.

Comments: ______

Sample D8-13 T4 B-8
Concentration 50 %
Initiation Date Apr 6/92

E.V.S. CONSULTANTS

Daphnia magna 21 D LIFE CYCLE TEST - WATER QUALITY DATA

E.V.S. Project No. 3/144-19.1
E.V.S. Work Order No. ________

Parameter	Date/Day of Test																					
			Apr 8		Apr 10			Apr 13		Apr 15		17/4			Apr 20		Apr 22		Apr 24			
	0	1	②	3	④	5	6	⑦	8	⑨	10	⑪	12	13	⑭	15	⑯	17	⑱	19	20	21
Temperature (°C)	22	22.5	22	22	22	23.5	23.5	22	22	22		23	23.5	24	23	23	22	23	23	24	23.5	24
D.O. (mg/L) (old solution)			10.7		9.0			9.3		8.7		8.6			7.3		8.1		7.5			8.0
D.O. (mg/L) (new solution)	8.4		9.2 ↓ 5 min 8.4		8.7			8.7		8.6		8.2			8.1		8.8		8.0			
pH	8.4		8.3		8.3			8.4		8.2		8.3			8.2		8.2		8.2			
Hardness (mg/L as $CaCO_3$)																						
Alkalinity (mg/L)																						
Conductivity (µmhos/cm)	500		500		500			500		500		550			550		550		550			

O = circle indicates solution replacement

Temperature is measured daily; dissolved oxygen is measured in old and new test solutions at each renewal; pH is measured at each renewal; other parameters are measured at the start and end of the test and at least once per week during the test.

Comments: ________

Sample 28-13 T4 6-7

Concentration 50 %

Initiation Date Apr 6/92

E.V.S. CONSULTANTS

Daphnia magna 21 D LIFE CYCLE TEST - WATER QUALITY DATA

E.V.S. Project No. 3/1004-13.1

E.V.S. Work Order No. ____________

Parameter	Date/Day of Test																					
			Apr 8		Apr 10			Apr 13		Apr 15		17/4			Apr 20		Apr 22		Apr 24			
	0	1	②	3	④	5	6	⑦	8	⑨	10	⑪	12	13	⑭	15	⑯	17	⑱	19	20	21
Temperature (°C)	22	22.5	22	22	22	23.5	23.5	22	22	22		23	23.5	24	23	23	22	23	23	24	23.5	24
D.O. (mg/L) (old solution)			9.8		8.7			8.7		8.7		84			7.2		8.1		7.5			8.0
D.O. (mg/L) (new solution)	8.5		9.2 45 min 8.3		8.7			8.5		8.6		82			8.1		8.8		8.0			
pH	8.4		8.3		8.3			8.4		8.3		83			8.3		8.2		8.2			
Hardness (mg/L as $CaCO_3$)																						
Alkalinity (mg/L)																						
Conductivity (µmhos/cm)	600		500		500			500		500		600			550		600		600			

O = circle indicates solution replacement

Temperature is measured daily; dissolved oxygen is measured in old and new test solutions at each renewal; pH is measured at each renewal; other parameters are measured at the start and end of the test and at least once per week during the test.

Comments: ____________________

Sample Days 8-13 = Y
Concentration 50 % (v/v)
Initiation Date Apr 6/92

E.V.S. CONSULTANTS

Daphnia magna 21 D LIFE CYCLE TEST DATA

E.V.S. Project No. 3/144-17 1
E.V.S. Work Order No. ____________

	Date/Day of Test																				
		Apr 8		Apr 10			Apr 13		Apr 15		17/4			Apr 20		Apr 22		Apr 24			
Replicate	1	②	3	④	5	6	⑦	8	⑨	10	⑪	12	13	⑭	15	⑯	17	⑱	19	20	21
A		m		m			m		m		M			m		m		m			m
T1 A-Y		✓		✓			10		28		31			27		32		✓			23
B		m		m			m		m		M			m		m		m			m
T1 B-Y		✓		✓			1		9		15			25		23		✓			18
C		m		m			m		m		M			m		m		m			m
T1 C-Y		✓		✓			14		34		29			19		27		✓			16
D		m		m			m		m		M			m		m		m			m
T2 A-Y		✓		✓			14		32		25			23		23		8			15
E		m		m			m		m		M			m				m			m
T2 B-Y		✓		✓			16		24		27			19		✓		19			17
F		m		m			m		m		M			m							
T2 C-Y		✓		✓			16		30		28			26		8		17 ×——			—
G		m		m							M			m		m		m			m
T3 A-Y		✓		✓			✓		4		17			29		27		10			13
H		m		m					m		M			m		m		m			m
T3 B-Y		✓		✓			✓		✓		✓			11		9		7			20
I		m		m			m		m		M			m				m			m
T3 C-Y		✓		✓			13		37		35			30		✓		27			20
J																					

D = dead female *Daphnia* S = stressed female *Daphnia* M = molt No. = number of young born O = circle indicates solution replacement

Comments: 50 % dilution with hard water
Day 2 T1 B-Y -- animal small & v. pale